U.S. DEPARTMENT OF COMMERCE

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

COAST AND GEODETIC SURVEY

Washington, D.C. 20235

EARTHQUAKES IN THE UNITED STATES 1963-64 AND AN EVALUATION OF THE DETECTION CAPABILITY OF THE UNITED STATES SEISMOGRAPH STATIONS

16 NOVEMBER 1965

Prepared for

ADVANCED RESEARCH PROJECTS AGENCY

under

ARPA Order No. 620

by the

SEISMOLOGY DIVISION
SEISMOLOGICAL RESEARCH GROUP

ERRATA

Page 16 - $\log N = (6.79 \pm 0.89) - (1.27 \pm 0.16)\, m_b$

Page 18 - $\log N = (4.41 \pm 0.26) - (0.83 \pm 0.07)\, m_b$

Page 19 - $\log N = (4.96 \pm 0.31) - (1.03 \pm 0.19)\, m_b$

Page 20 - $\log N = (5.06 \pm 0.27) - (1.25 \pm 0.15)\, m_b$

Page 107 - It is a pleasure to acknowledge the assistance of personnel of the VELA Seismological Center, AFTAC and the Seismic Data Laboratory, Teledyne, Inc. who made the "network" program available to us and provided valuable discussions regarding its operation. Background noise data were supplied by a number of station operators along with data regarding station instrumentation and operative magnification. We regret that space does not permit us to acknowledge each contribution individually.

Particular recognition is given the administrative supervision provided by Mr. L. M. Murphy, Chief, Division of Seismology, and to W.H. Dillinger, Jr. who aided in compiling the background noise data.

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FINAL REPORT

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TASK 5b

by

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PREFACE

Since the inception of its program in Seismology, the Coast and Geodetic Survey has actively collected, analyzed, and published data concerning earthquakes in the United States. The results are published in the yearly series, United States Earthquakes. Notwithstanding this effort, complete seismicity studies are lacking for most of the country primarily due to the incompleteness of magnitude data for a majority of the earthquakes.

Detailed seismicity studies are fairly complete only for limited areas of dense station coverage. In California, where magnitudes of all located earthquakes have been computed for many years, it has been possible to make statistical studies of the data. Recently, however, improvements in seismograph instruments and better geographic distribution of recording sites, along with advances in reporting and processing techniques, have greatly increased the number and reliability of earthquake epicenters located elsewhere in the United States. With the routine determination of magnitudes, which was begun by the Coast and Geodetic Survey in 1963, a meaningful statistic is now available from which seismicity studies can be made for the entire United States.

To make such studies, it is desirable to know the approximate lower limit of magnitude for which we may expect all earthquakes to be located. Accordingly, in this report, the geographic

distribution and operating characteristics of the United States network of seismograph stations are used to provide this knowledge. The method used is the statistical approach of Booker (1964) with minor modifications. Results are given in terms of the probability of detecting an event, with known hypocenters and magnitude, by at least five stations of the total network of seismograph stations. Five is the minimum number of stations required for a hypocenter computation by the Coast and Geodetic Survey's hypocenter program.

This report is presented in two parts. Part I is a presentation of the seismicity based on earthquakes located in the United States during 1963-64 as reported in Preliminary Determination of Epicenters. Part II is an evaluation of the capability of the existing network of seismograph stations.

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Part I

United States Seismicity for 1963-64

1. Introduction

The Coast and Geodetic Survey began reporting earthquake magnitudes during 1963. These magnitudes, which are based on the m_b magnitude scale of Gutenberg and Richter (1956) as adopted by the Coast and Geodetic Survey, provide the needed parameter, in addition to the hypocenter, for complete seismicity studies. This study is based on earthquakes reported on the Preliminary Determination of Epicenter (P.D.E.) cards of the Coast and Geodetic Survey. It is, accordingly, recognized that more complete data will be available in some areas with the publication of local station bulletins.

Four types of presentations are made: (1) a chronological list of earthquakes; (2) a magnitude map showing the geographical distribution of earthquakes whose magnitudes are greater than, or equal to, 3.0; (3) a presentation of frequency versus magnitude for the total United States and for individual regions of high seismicity; and (4) a "seismicity" map giving a quantitative measure of relative seismic activity.

Chronological listings of earthquakes, along with epicenter maps with symbols for magnitude and depth, have been used for many years to present seismic activity. More recently, however,

work has been directed toward developing quantitative measures of seismicity. Båth (1956) discussed the different definitions and gave references to the pertinent literature up to 1956.

Two basic methods of presenting quantitative seismicity now widely used are: areal summing of energies of individual shocks (Båth, 1953), and "seismic activity" based on the frequency-energy relationship of earthquakes (Riznichenko, 1959). Båth (1960) further developed the areal summing method of presenting quantitative seismicity. By this method, all earthquakes from the threshold magnitude for the entire region of study to the highest magnitude attained in each unit area are summed. The method of Riznichenko, which he has further developed (Riznichenko, 1964), establishes a level of seismic activity for each unit area based on the frequency-energy plot of earthquakes within the area. The resulting map displays the areal variation of the recurrence rate of earthquakes of a specified energy level. The method assumes the slope of the frequency-energy plot to be constant throughout the region of study. It requires accurate knowledge of the frequency-magnitude relationship.

St. Amand (1956) has suggested the sum of the square-roots of energies from individual earthquakes (a variation of the areal summing technique) as a quantitative measure of seismicity

inasmuch as the results are porportional to strain release (Benioff, 1951). For this study we prefer St. Amand's method to illustrate areal strain release patterns. By this method no assumptions are required regarding secular seismicity.

2. Geographical Distribution of Earthquakes

For convenience of presenting detail, the United States is divided arbitrarily into eight regions as shown on Figure 1. These regions are in no way related to physiographic, geologic, or seismic provinces.

During the two year period covered by this report, the Coast and Geodetic Survey reported epicenters of 691 earthquakes in the conterminous United States as a part of the Preliminary Determination of Epicenters program. A chronological listing of these events is presented in Table 1. Their geographic distribution is shown on Figures 2 to 7.

Earthquakes are distinguished by magnitude in ranges of 3.0-4.0, 4.0-5.0, 5.0-6.0. No earthquake with a magnitude greater than 6.0 occurred in the conterminous United States during the 1963-64 period. The presentation of all earthquakes in the magnitude range 3.0-4.0 results in somewhat biased values of earthquake density for areas having good station coverage. We will return to this point subsequently and discuss it in detail in Part II of this report.

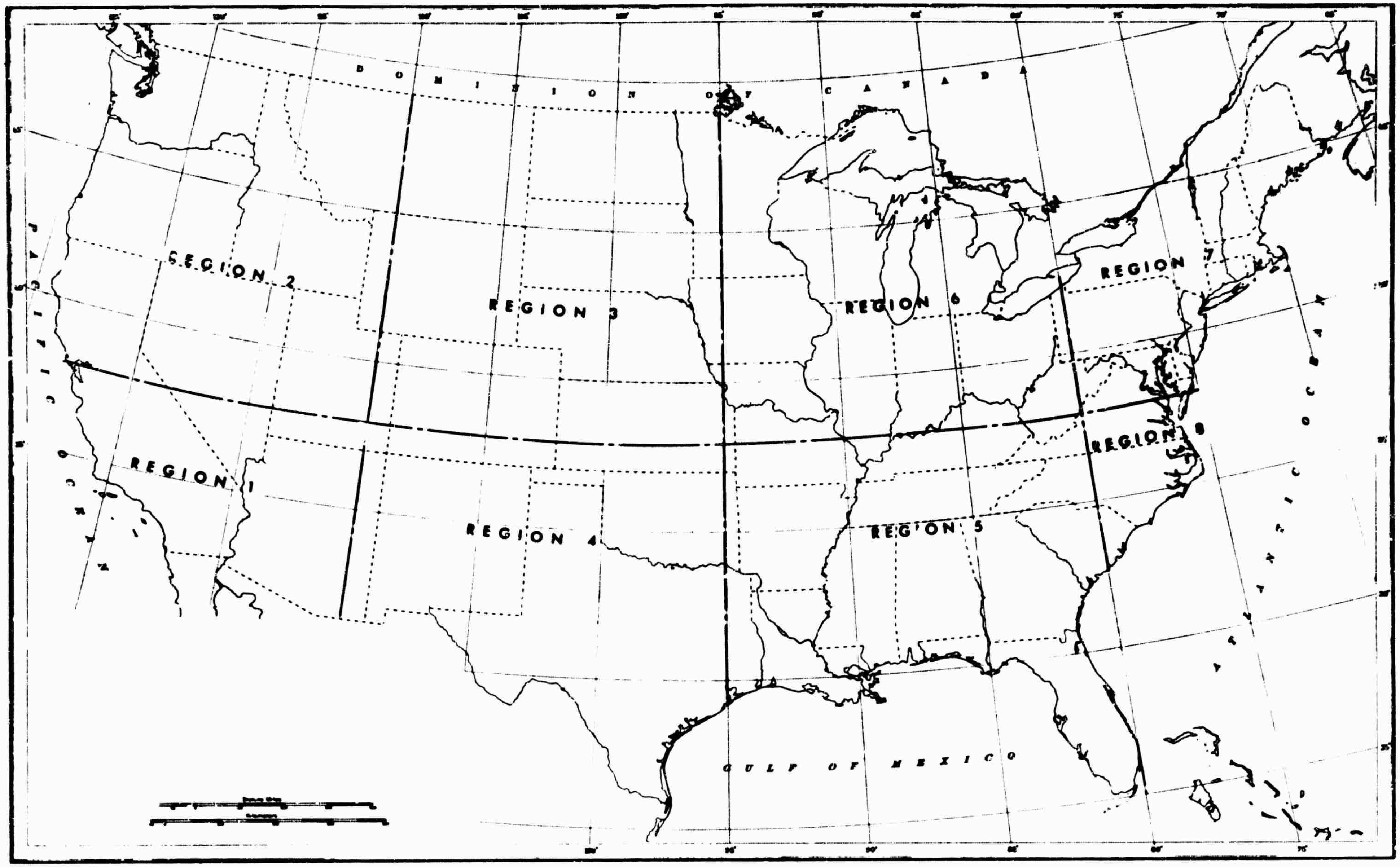

Figure 1. Regional Divisions of the United States for the Presentation of 1963-64 Seismicity.

Of the total events reported on P.D.E. cards during 1963 and 1964 approximately 90 percent had epicenters in the seismic regions of the western United States west of the eastern edge of the Rocky Mountains. In terms of numbers of earthquakes, the region designated by Heck (1938) as the "western mountain region," displays the highest seismicity (see Figures 2 and 3). Figure 3 displays four highly active areas. The two which show the highest activity in terms of numbers of earthquakes are in central Idaho, centered at 44.5°N-114.5°W, and an elongated east-west area in extreme northwestern Wyoming and southwestern Montana. Two other areas displaying high activity are eastern Idaho at 43.0°N-111.5°W and southwestern Nevada at 39°N-118.5°W.

The central Idaho earthquakes are closely grouped in time as well as space. The sequence began on September 6, 1963 and continued with a high level of activity until December 23, when one event registered a magnitude (m_b) of 5.1. Following this earthquake the activity decreased rapidly. Similarly, the major activity in southwestern Nevada falls within a thirty-six day period following a magnitude 5 0 earthquake on October 23, 1964.

Along the Pacific coast the greatest activity occurred in southern California (see Figures 2 and 3). The level of seismic

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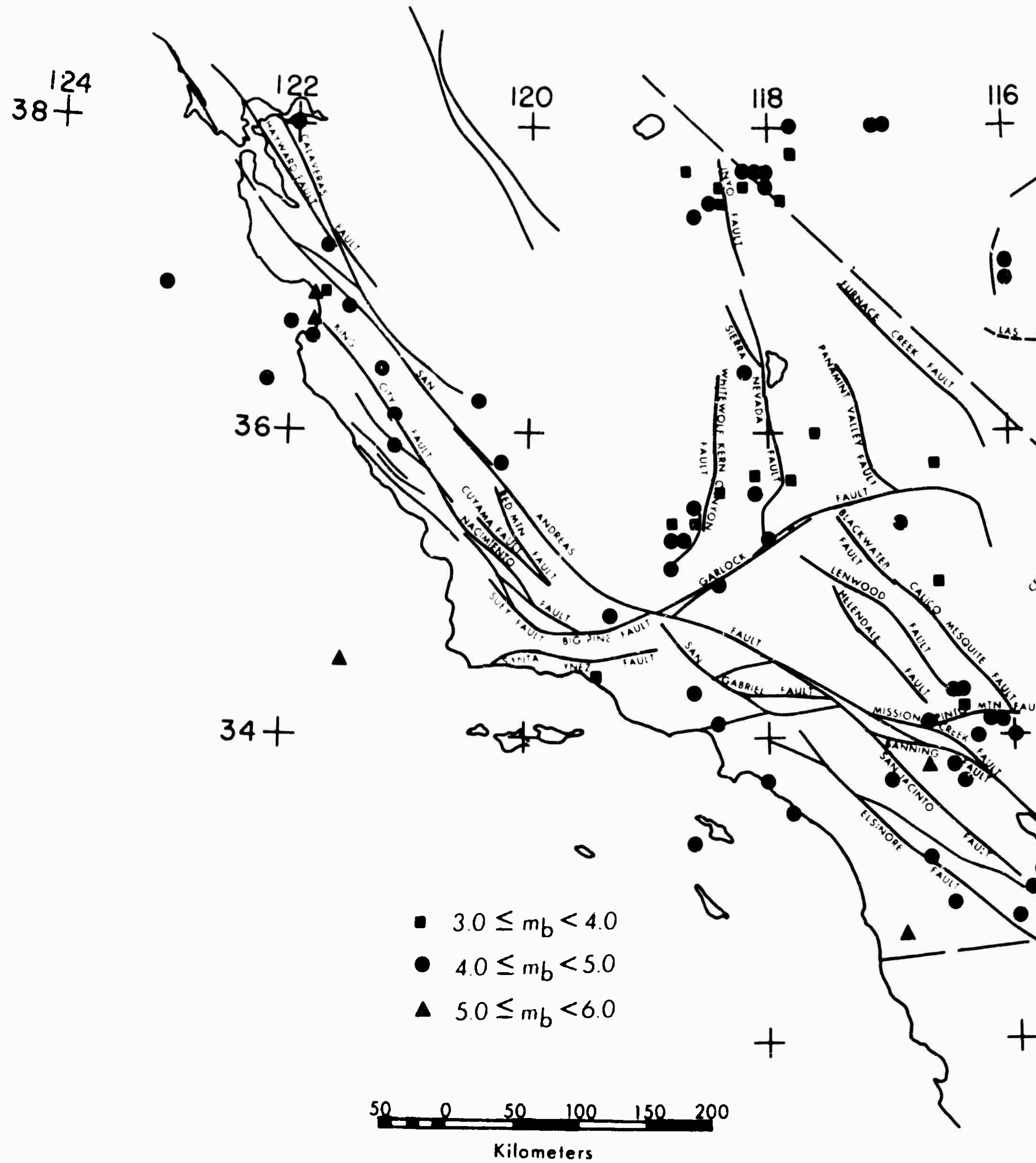
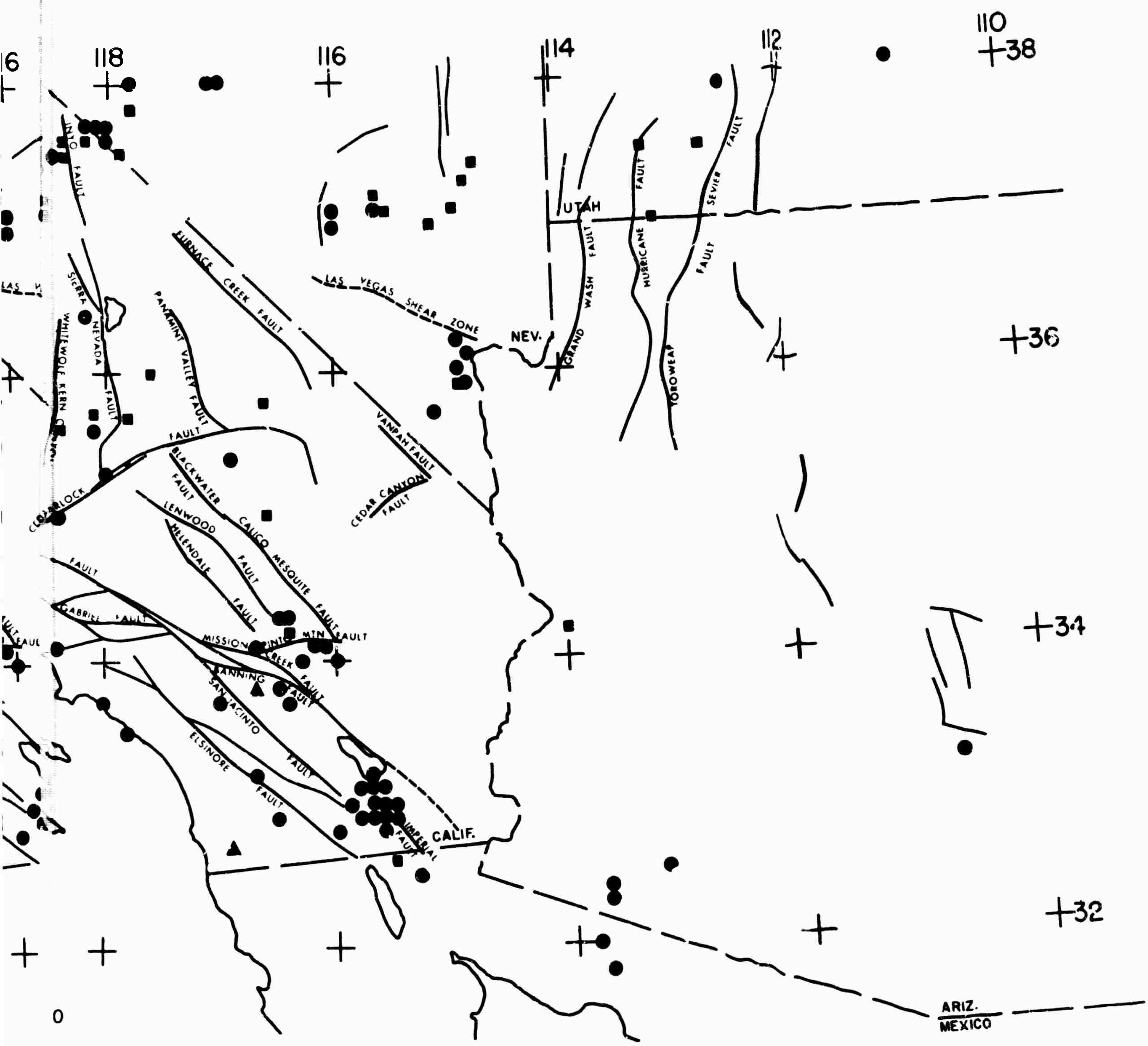


Figure 2. Earthquake Epicenters in Region

B



gion Earthquake Epicenters in Region 1 During 1963-64.

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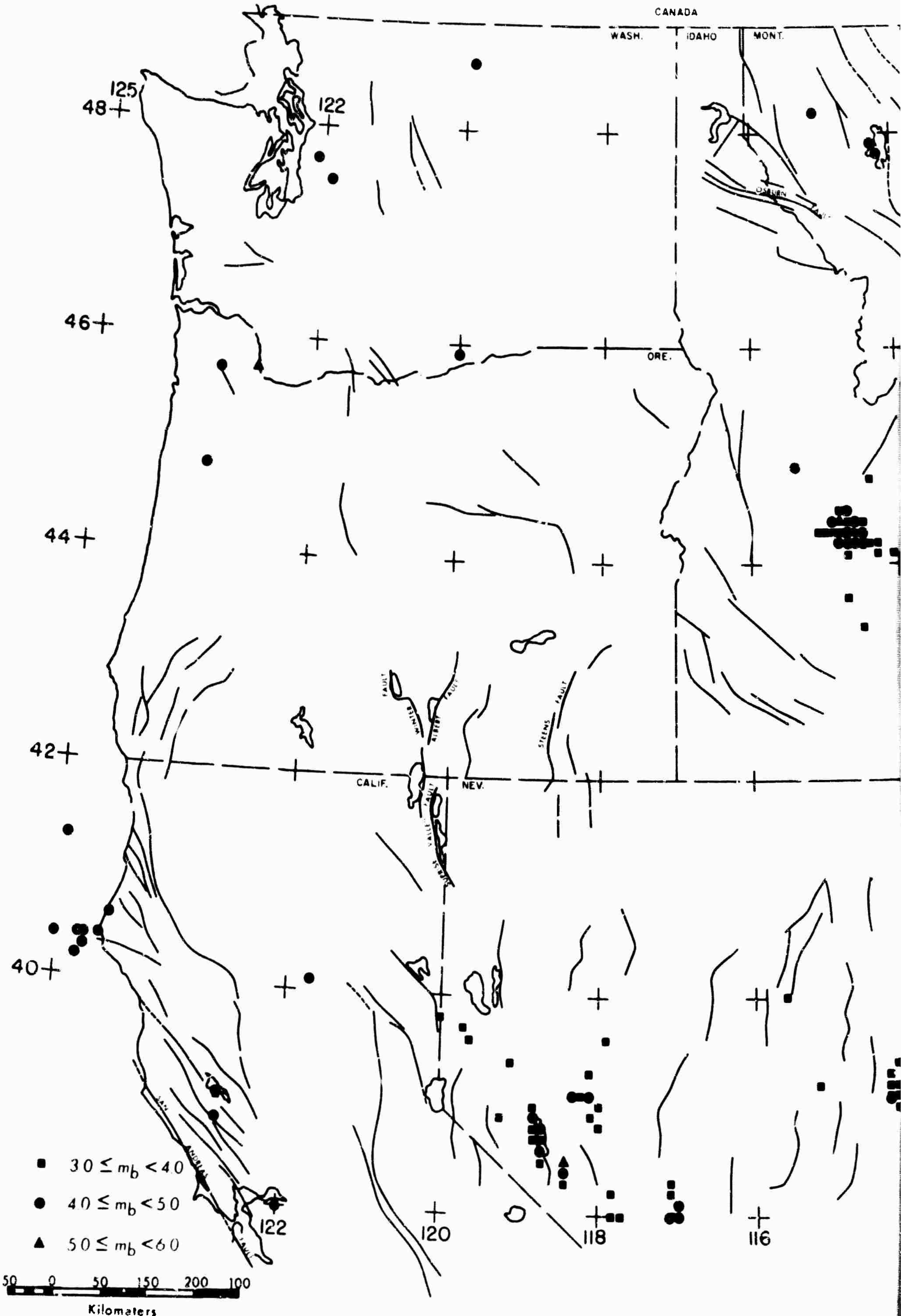

Figure 3 Earthquake Epicenters in Region 2 During

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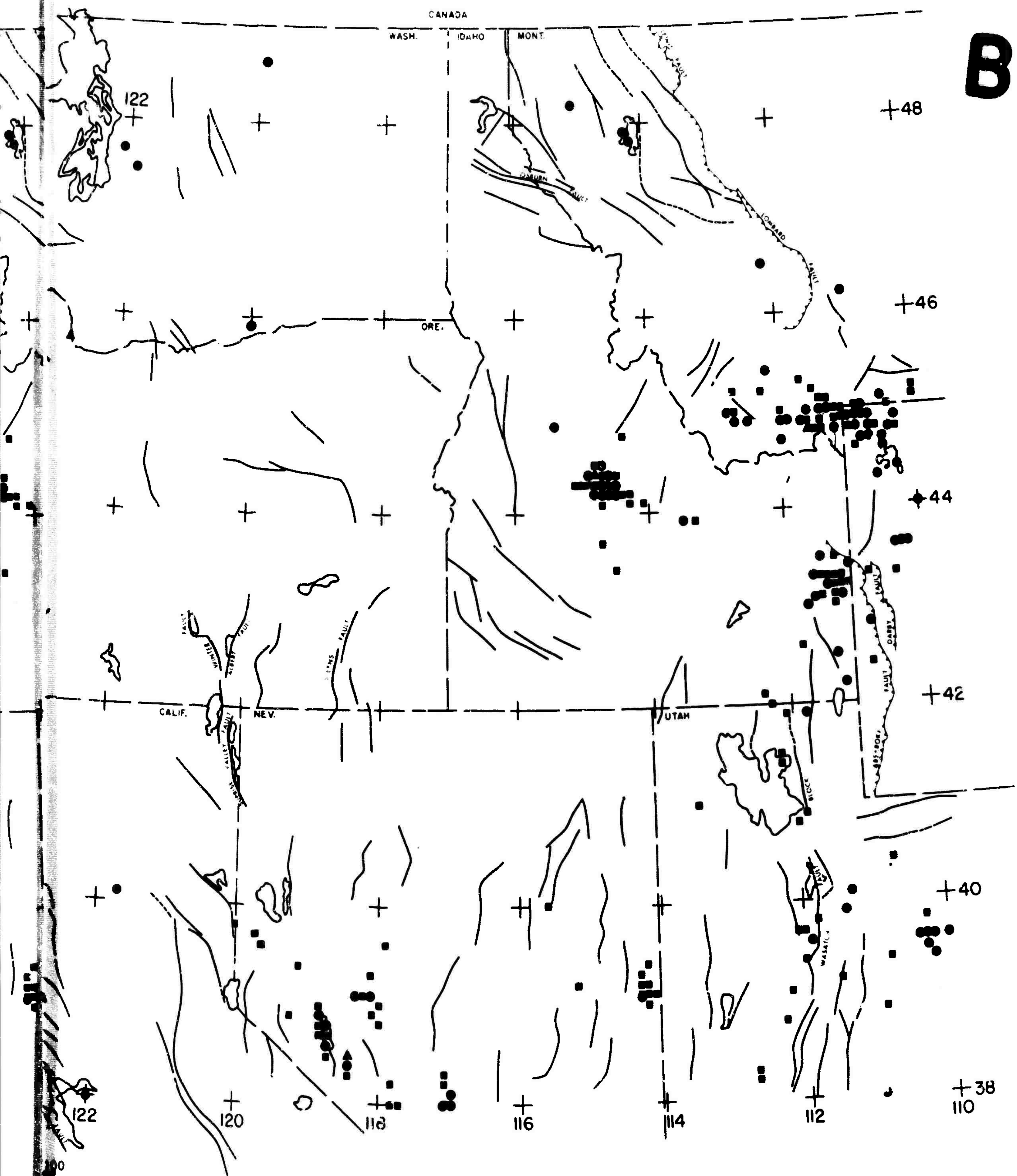

Figure 3. Earthquake Epicenters in Region 2 During 1963-64.

activity in southern California south of 36°N is more than six times greater than in northern California. Gutenberg and Richter (1954) suggest that this is, in part, a temporary condition. They observe that earthquake activity has been abnormally low in central California, relative to southern California, since the San Francisco earthquake of 1906. The data of this report indicate a continuation of this condition.

An area of dense earthquake activity occurred in southern California (see Figure 2). These events, which show congruity with the Imperial Fault, also display close time correlation, most of them having occurred on October 27 and 28, 1963. No other significantly dense occurrence of earthquake activity is noted along the Pacific coast.

Historically, the most active seismic region in the United States has been along the Pacific coast, especially along the San Andreas and associated fault systems of California. That the data of this report fail to support this historical trend is largely due to the way in which it is presented. For if we limit our study to earthquakes of magnitude 4.0 or greater, the Pacific coast displays the greatest activity. Improved instrumentation along with better geographic distribution of recording sites in the western mountain region allows increasingly larger numbers of minor earthquakes, which previously

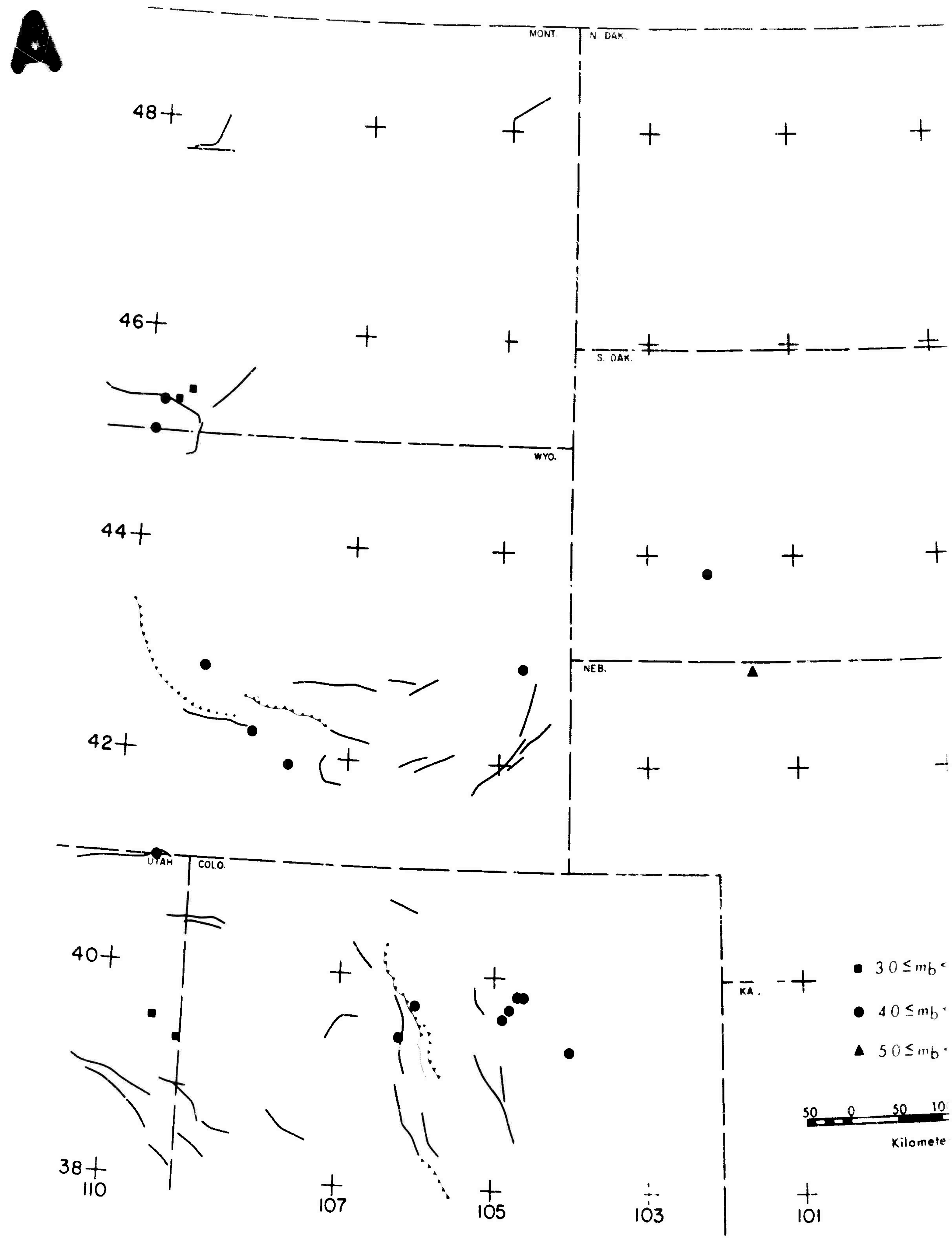

Figure 4. Farthquake Epicenters in Region 3 During 1963-64.

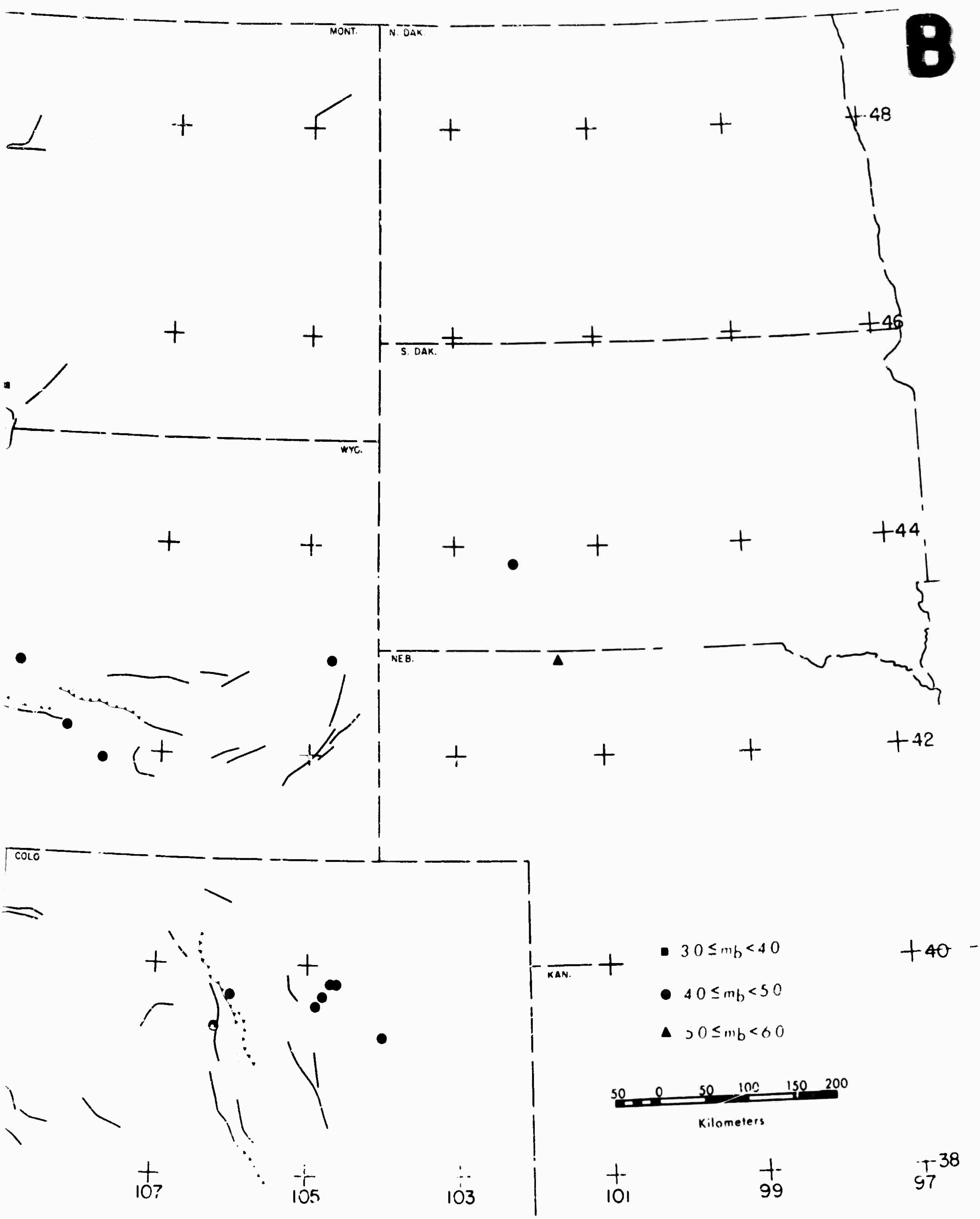

Figure 4. Earthquake Epicenters in Region 3 During 1963-64.

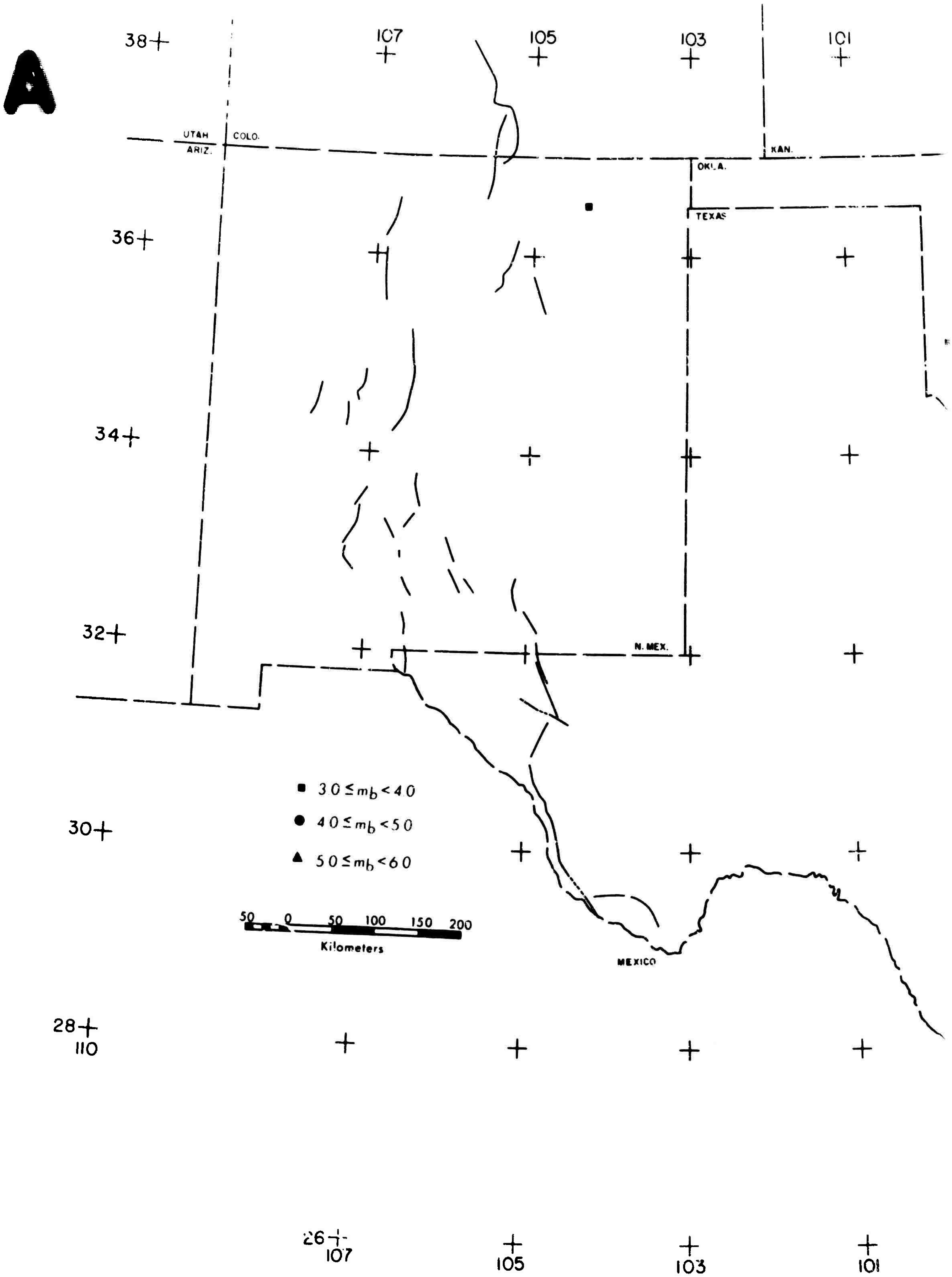

Figure 5. Earthquake Epicenters in Region 4 During 1963-64.

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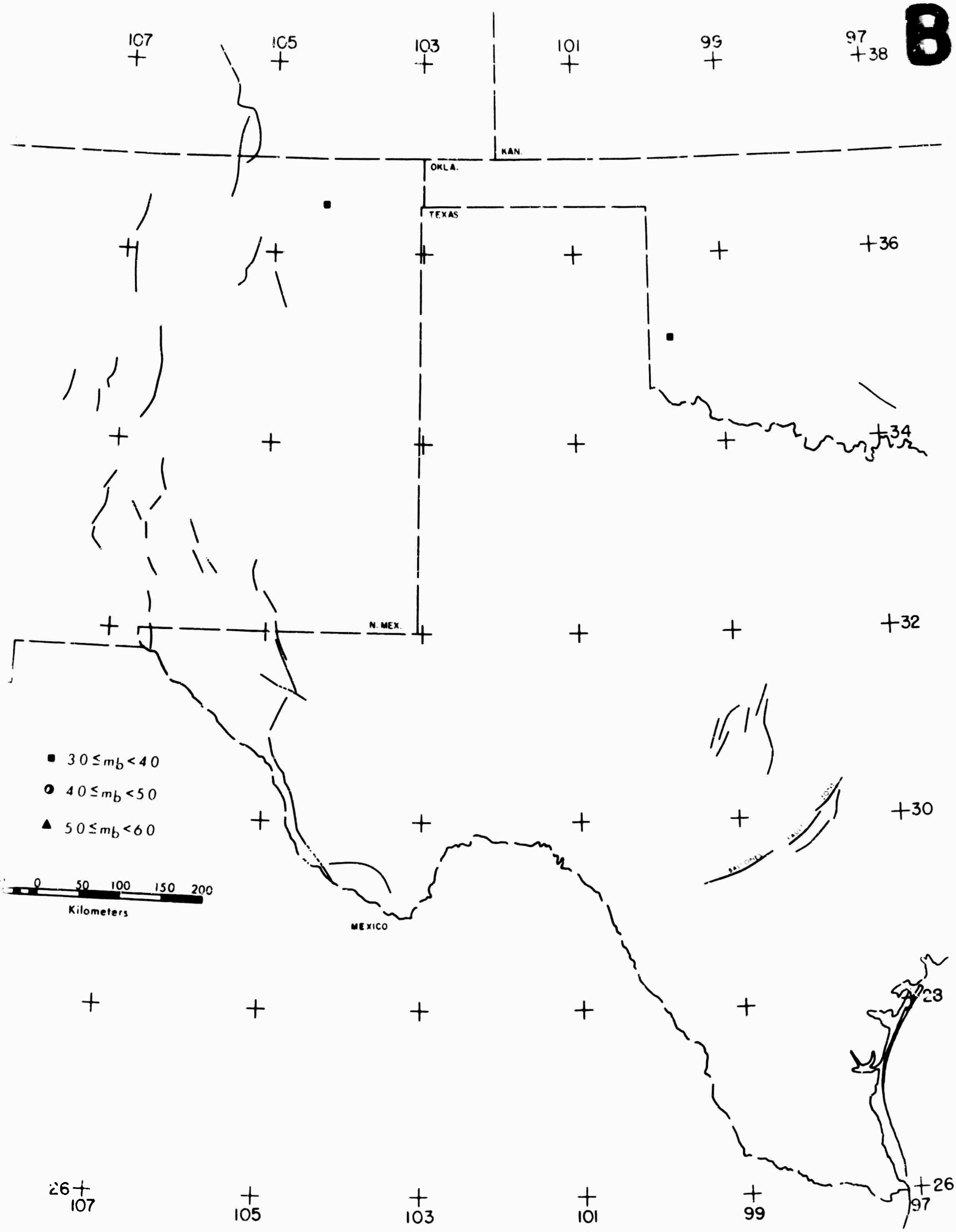

Figure 5. Earthquake Epicenters in Region 4 During 1963-64.

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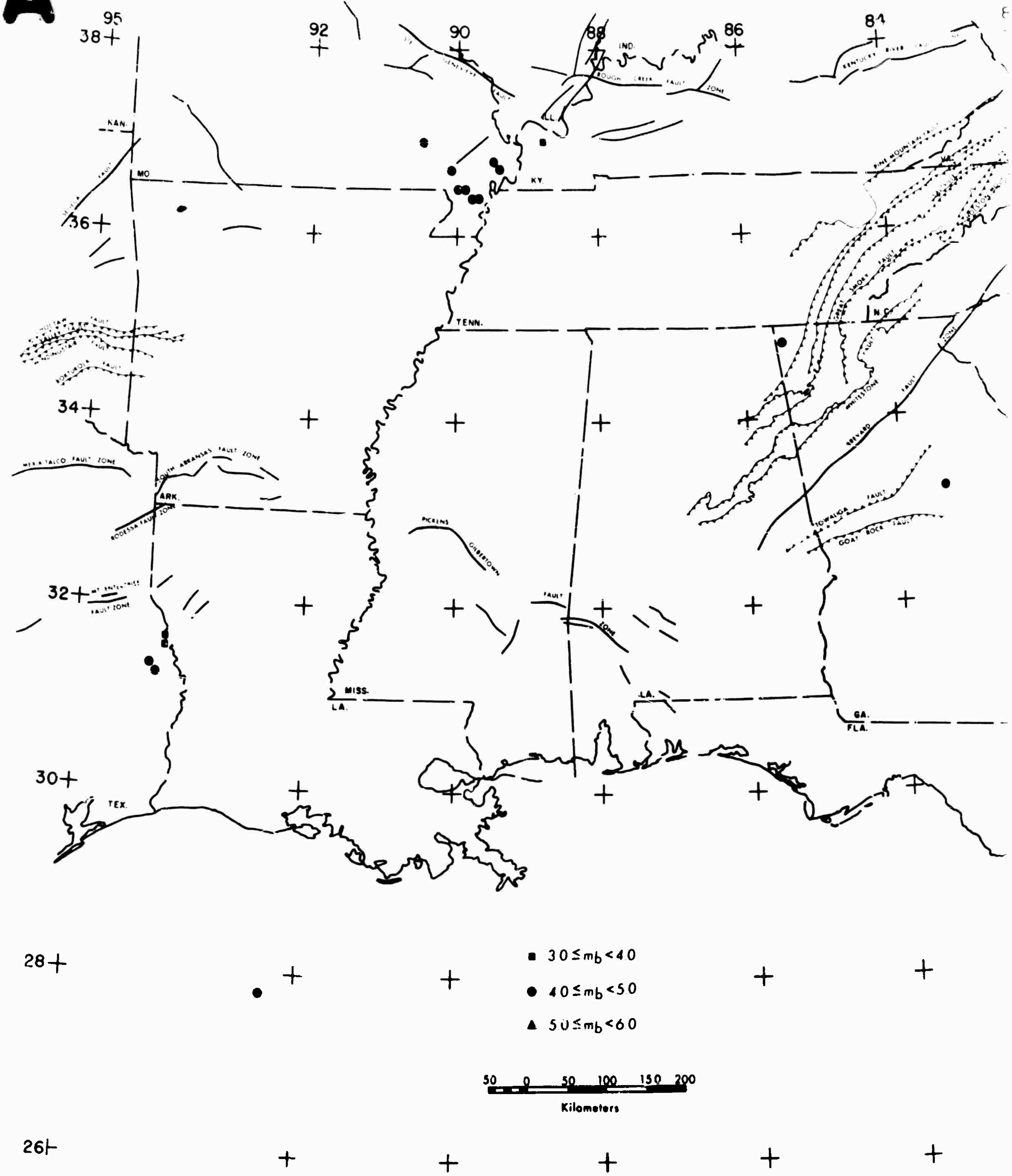


Figure 6. Earthquake Epicenters in Region 5 During 1963-64.

B

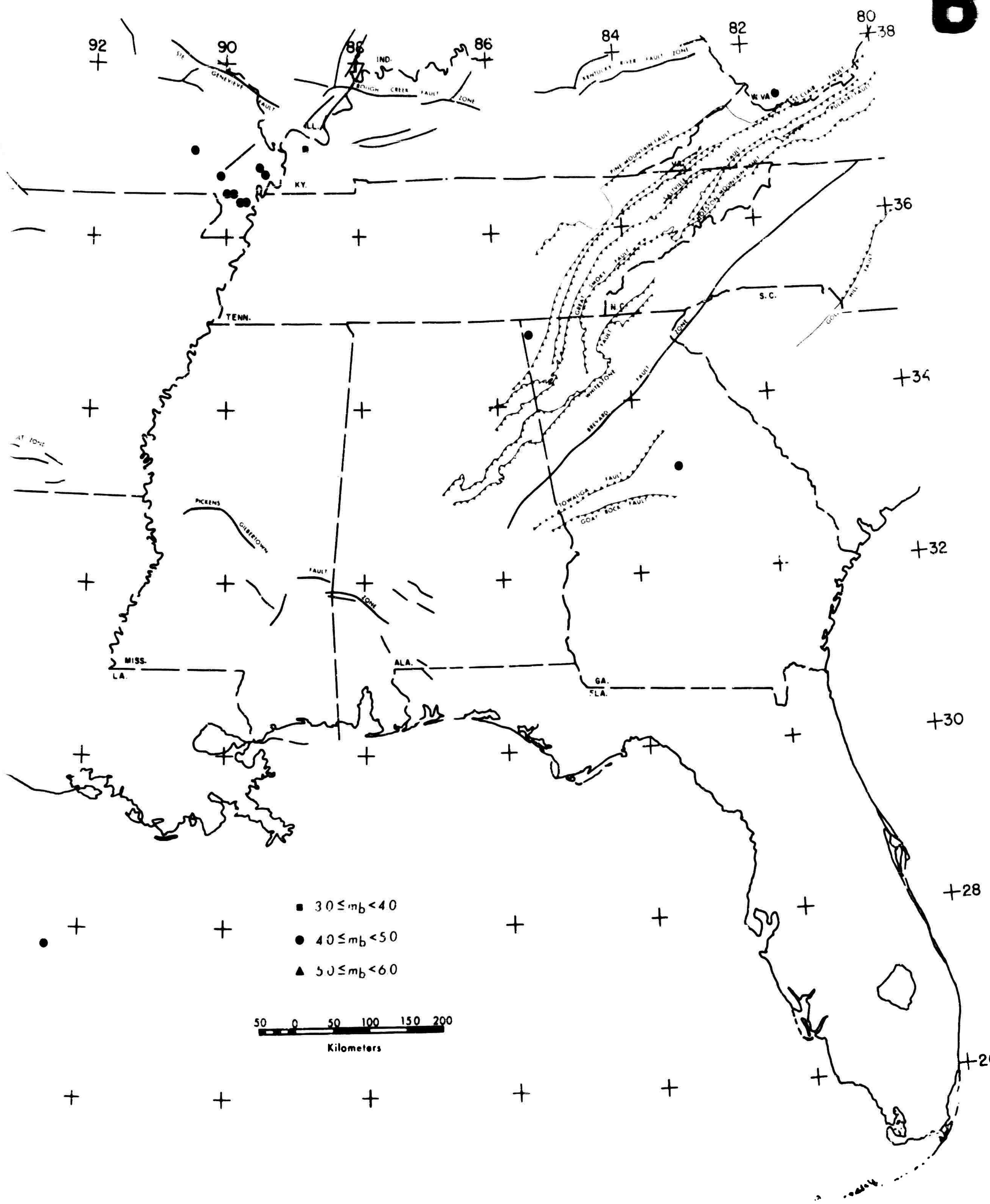


Figure 6. Earthquake Epicenters in Region 5 During 1963-64.

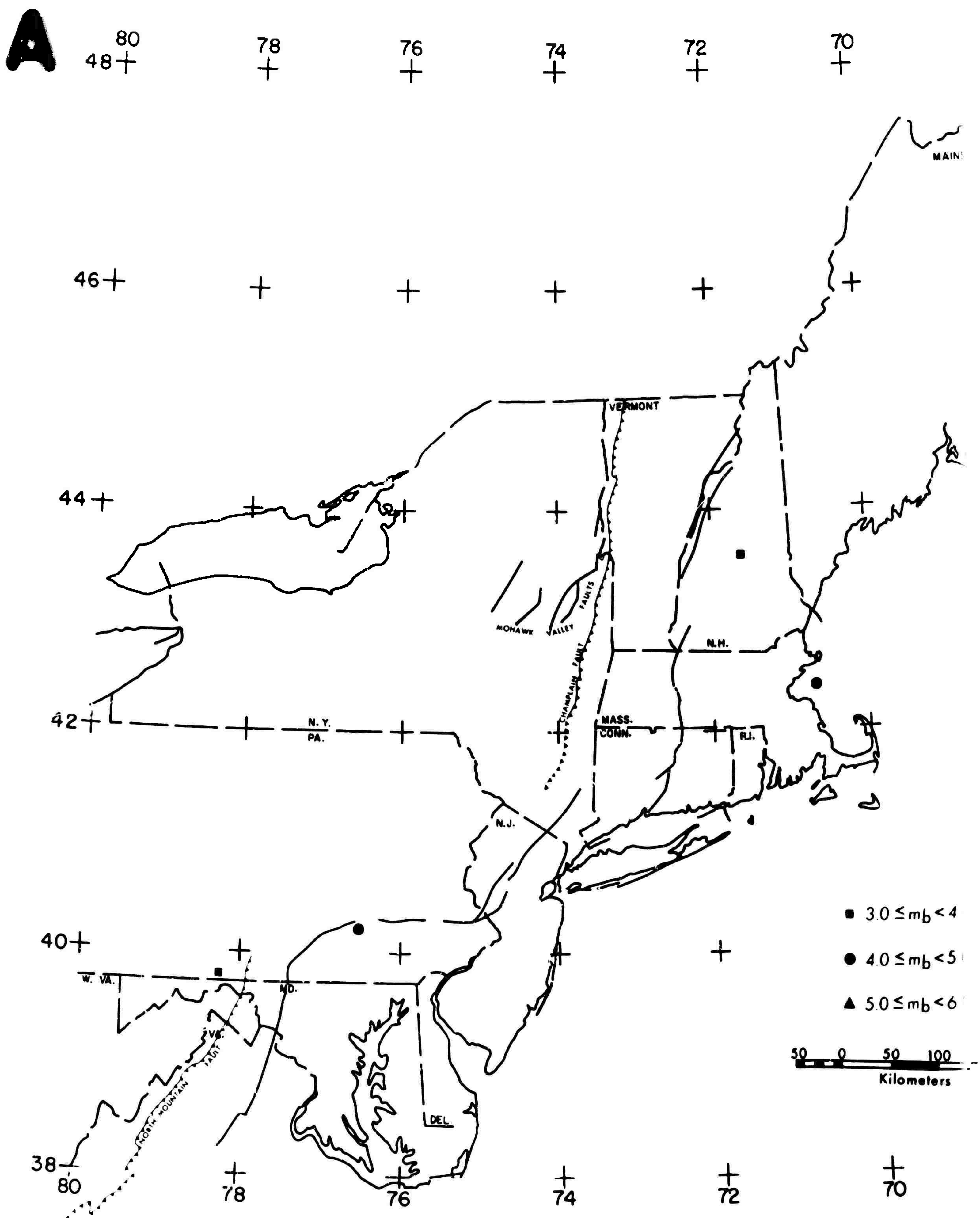


Figure 7. Earthquake Epicenters in Region 7 During 1963-64.

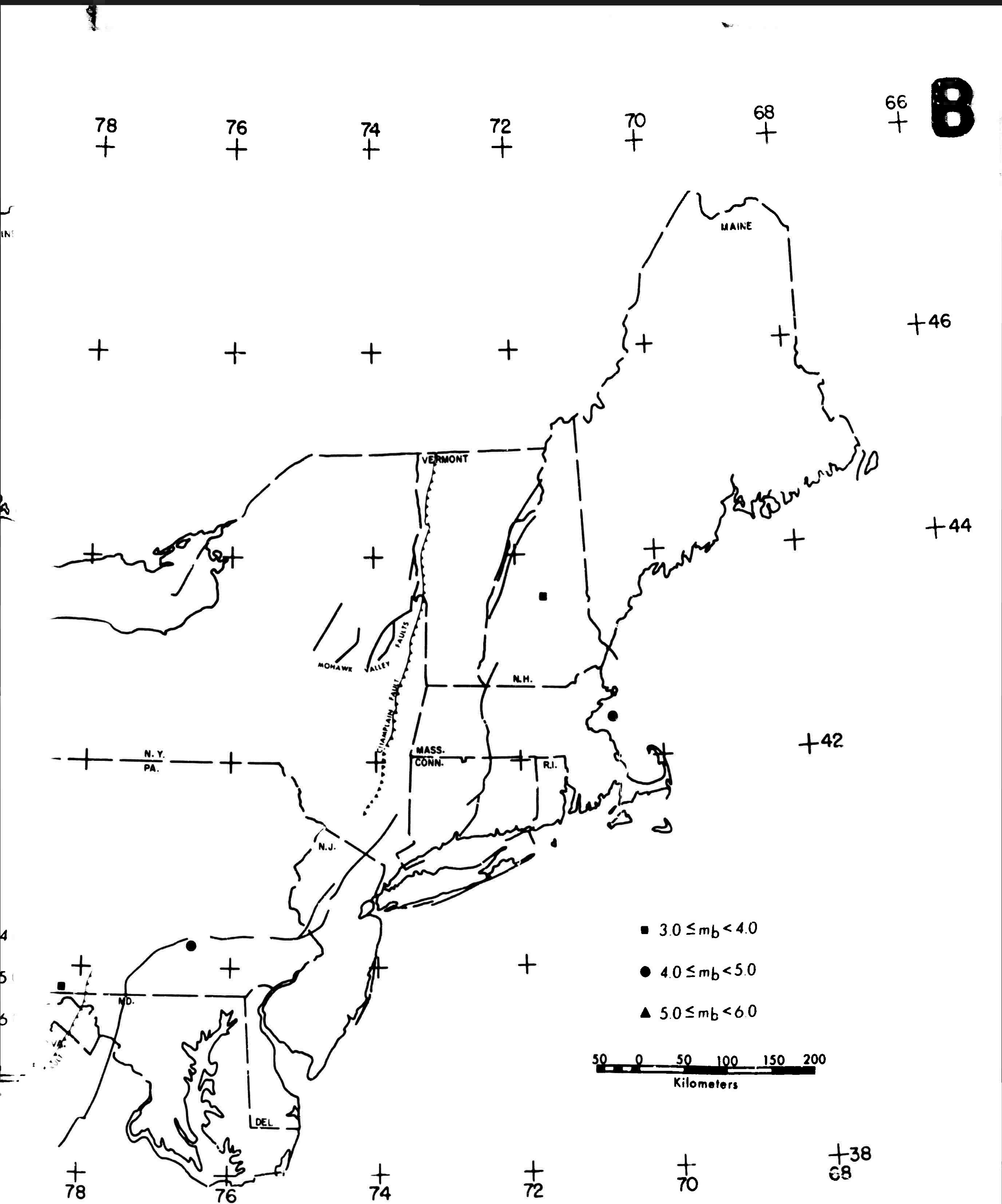


Figure 7. Earthquake Epicenters in Region 7 During 1963-64.

would have gone unreported, to be located in this region and their magnitudes determined. The location of low magnitude events in California and adjoining areas of Nevada and Oregon is accomplished by the two seismograph networks centered at Berkeley and Pasadena. Earthquakes within this region whose magnitudes are less than about 4.0 are generally not located for P.D.E. Therefore, for earthquakes of magnitudes less than 4.0, there is no consistency of the data from P.D.E. cards for different regions of the United States. In some areas this condition is due to incomplete reporting of data, while in other areas it is due to the limitations of the network detection capability.

East of the Rocky Mountain front, earthquake activity is very low (see Figures 4 to 7). The highest activity, in terms of number of earthquakes, is in the well known seismic region of southeast Missouri (see Figure 6).

3. Depth of Focus

In the case of shallow earthquakes, with which this study is concerned, the depth of focus is the most difficult hypocenter parameter to determine. Depth determination for low magnitude earthquakes within the earth's crust by least squares solution of the travel-time data is subject to gross error, which cannot be easily evaluated, due to variations in regional travel time. The accuracy has been said to be on the order of 25 km,

but computations based on recordings of nuclear explosions (Herrin and Taggart, 1962) show this estimate to be somewhat optimistic for some areas. The limitations on the method, especially for low magnitude crustal events which are recorded only locally and regionally, have been long recognized by the Coast and Geodetic Survey. Accordingly, depths are often restricted to conform with historical accounts of depths of earthquakes in the epicenter area.

The focal depth resolution may be expected to be more accurate in areas of high station density where at least one station is often near enough to the epicenter to record a direct P-wave. Such areas are southern and central California, southwest Montana, and southeast Missouri.

Separate maps illustrating focal depths were not prepared for this report because the narrow range of depths displayed by the data does not exceed the expected error. However, several observations may be made. All of the earthquakes have depths within the earth's crust. Earthquakes in southern California generally have depths from 8 km to 18 km. Northward in California depths range from 14 km to about 30 km.

A similar range of depths is displayed in the western Basin and Range province, while in the eastern Basin and Range the depths are closely grouped at about 33 km. This grouping is misleading, however, inasmuch as many of the earthquakes in this region are restrained at a depth of 33 km. A number of events in central Idaho and in the Yellowstone Park and adjacent

areas had depths between 40 km and 50 km. In the only significant area of seismic activity east of the Rocky Mountains, that of southeast Missouri, the focal depths ranged generally from 18 km to 25 km.

4. Frequency versus Magnitude

An important method of displaying seismicity is to construct recurrence curves of earthquake magnitude versus frequency of occurrence. These recurrence curves have several important applications. Comparison can be made of levels of activity for different regions. If they can be constructed in sufficient detail, it is possible to construct maps of "seismic activity" in the manner described by Riznichenko (1959). They may also serve as the basis for statistical probability studies of earthquake occurrence.

Such curves have been constructed for the entire United States (see Figure 8) and for three seismic regions: southern California; northern California, which includes western Nevada; and the eastern Basin and Range (see Figures 9 to 11). Southern California and northern California are divided approximately on the basis of the area covered by the two networks of seismograph stations-- the southern network centered at Pasadena, and the northern network centered at Berkeley. The eastern Basin and Range is used here loosely to describe the area of high seismicity extending from Arizona to Montana along the Wasatch Fault Block and associated faults to the north and south along the same trend.

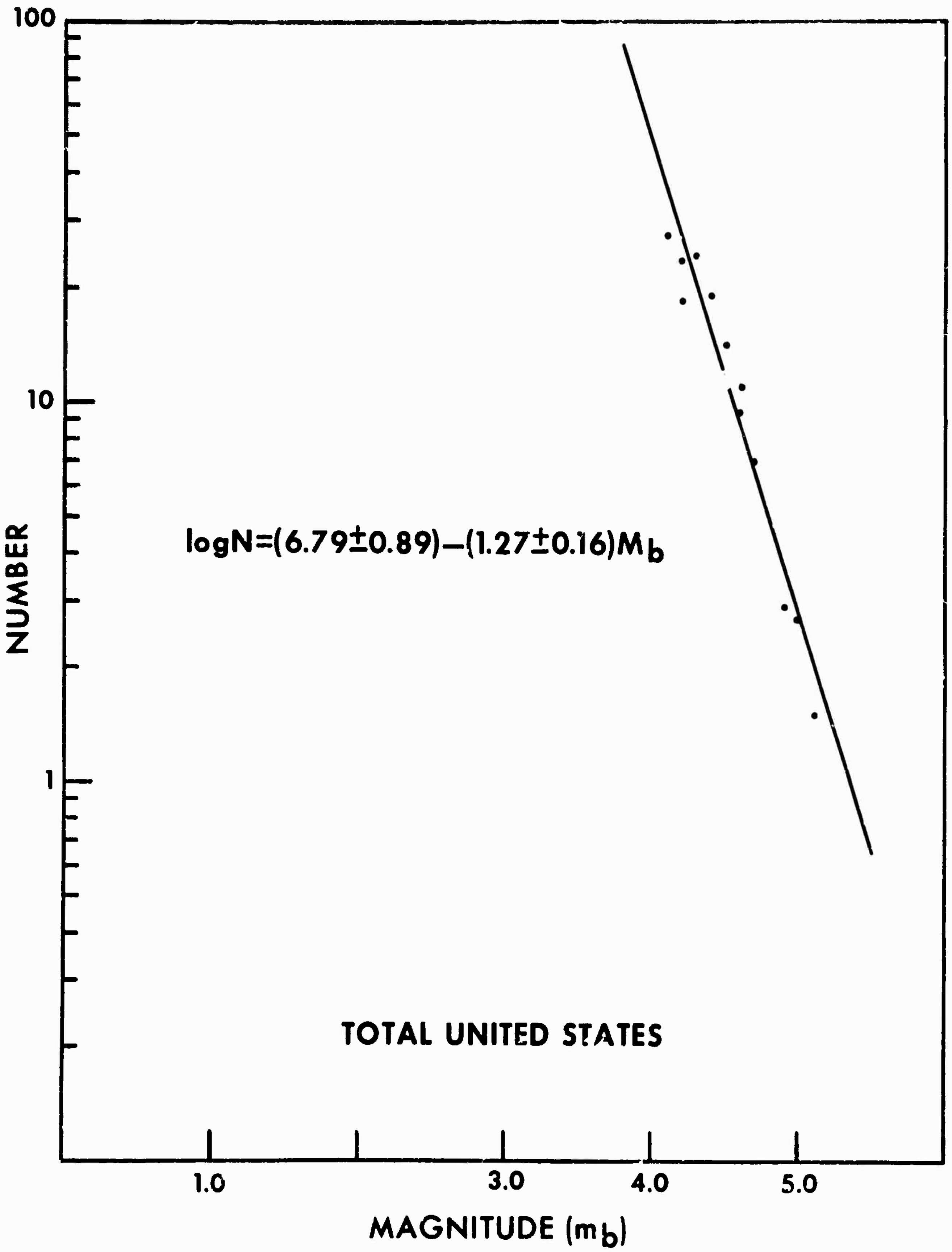


Figure 8. Earthquake Recurrence Curves for the Conterminous United States Based on 1963-64 Data.

To minimize the effect of incomplete listing of the smaller magnitudes, the smallest magnitude considered in constructing the recurrence curves is $m_b = 4.0$. An impirical expression of the form

$$\log N = a - bm_b$$

has been derived by the least square method for each set of data. The slope b varies from 0.83 in southern California to 1.27 for the total United States.

The recurrence curves of Figures 8 to 11 are based on an extremely limited range of magnitudes as well as on a limited data sample. We must then consider whether or not they can be extrapolated to lower and higher magnitudes. In addition, the question arises regarding this representation of secular activity. In view of the limited sample of data treated here, we prefer to restrict the recurrence curves to comparisons for the time covered by the report.

That the frequency of earthquakes increases with decreasing magnitude has been demonstrated for California as far down as magnitude 3.0 (Niazi, 1964; Allen, et al., 1965). During the course of this investigation detailed reports of local earthquakes, in the area which has been termed loosely here as the eastern Basin and Range, were compiled for a two month period from March 1, 1963 to May 1, 1963. On the basis of these data sixty-one events were located using a minimum of three stations. Of this number, thirteen events were recorded at five stations or more (the minimum number required for P.D.E.), which were not previously reported on P.D.E. cards. Although magnitudes were

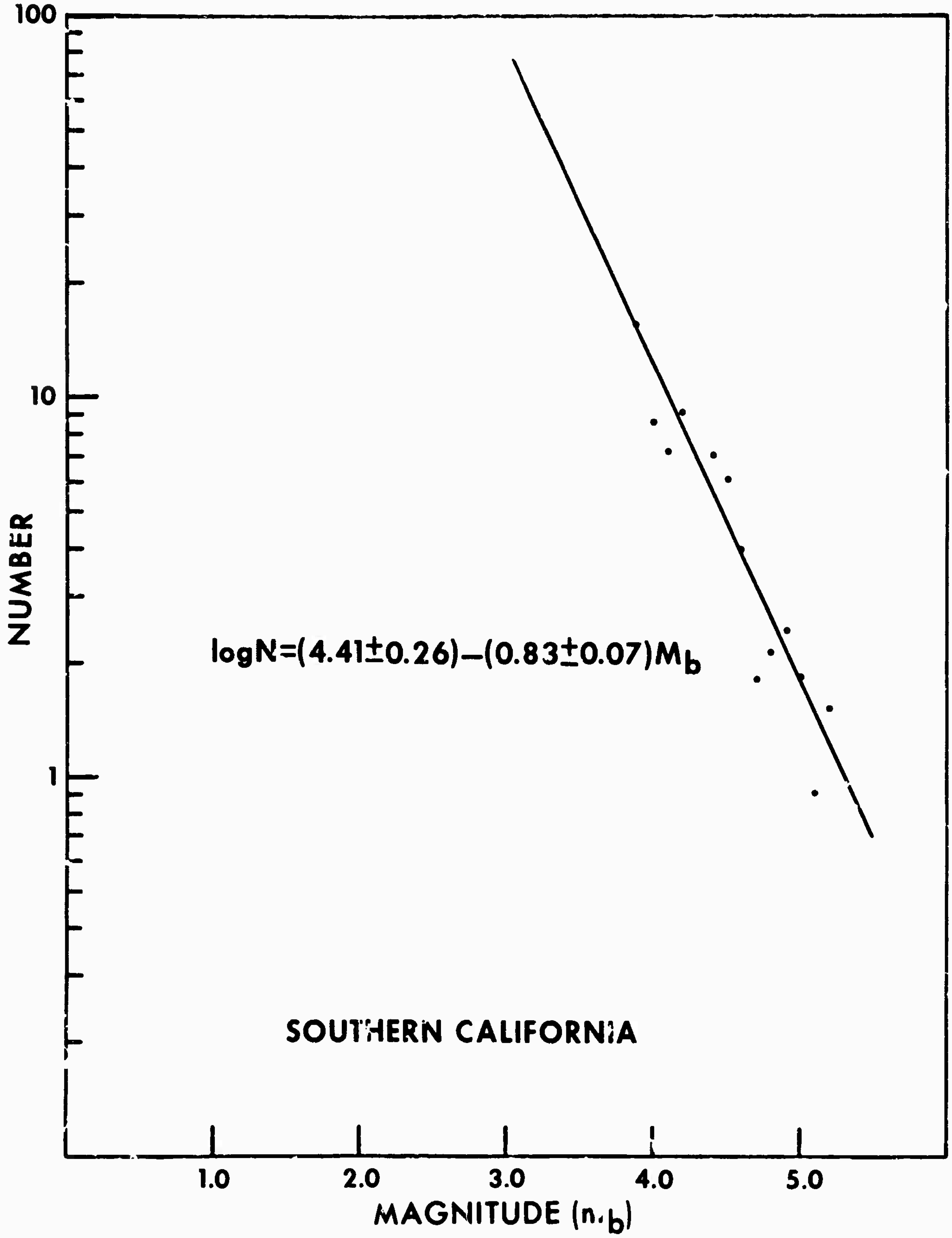


Figure 9. Earthquake Recurrence Curves for Southern California Based on 1963-64 Data.

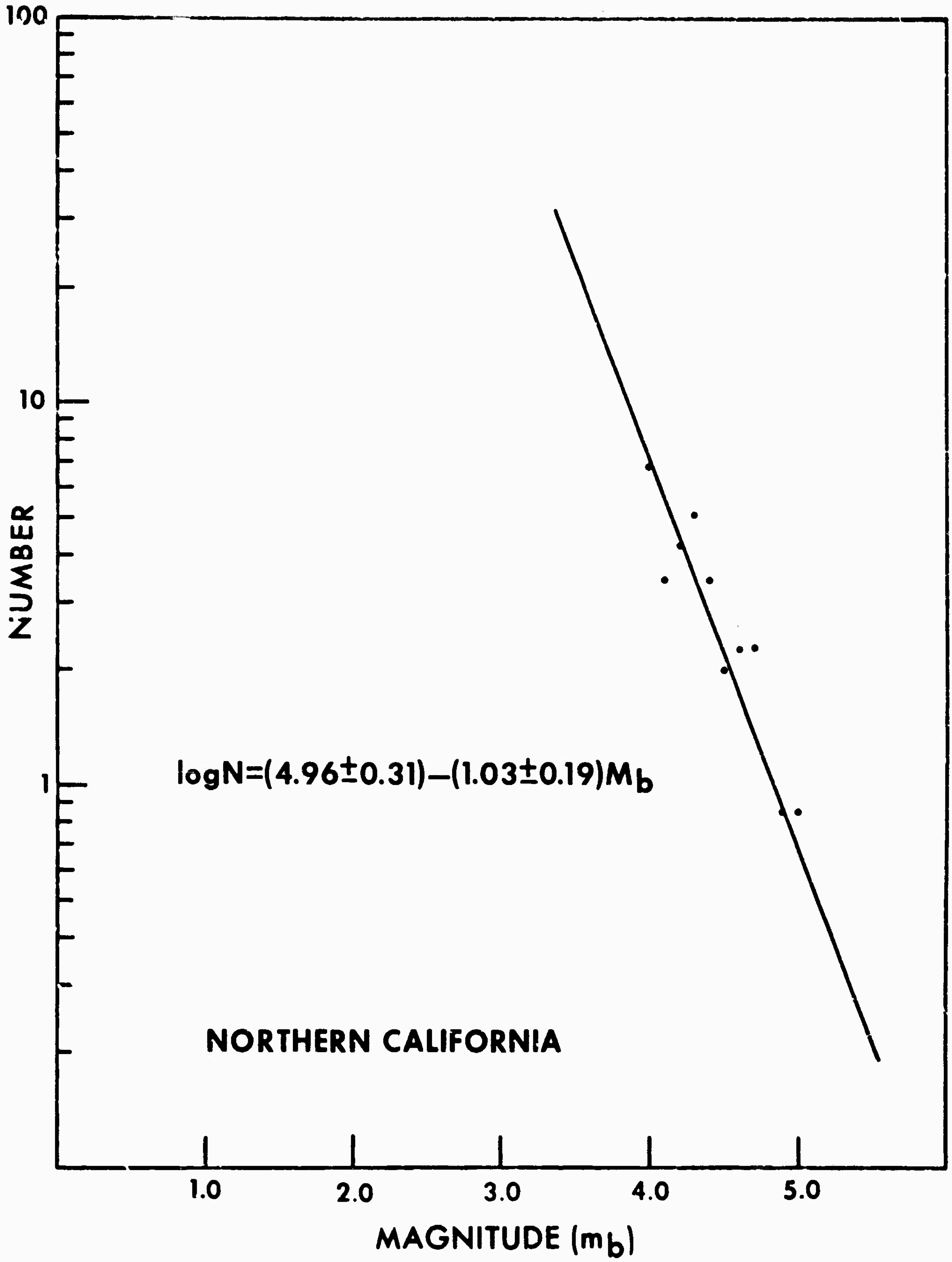


Figure 10. Earthquake Recurrence Curves for Northern California Based on 1963-64 Data.

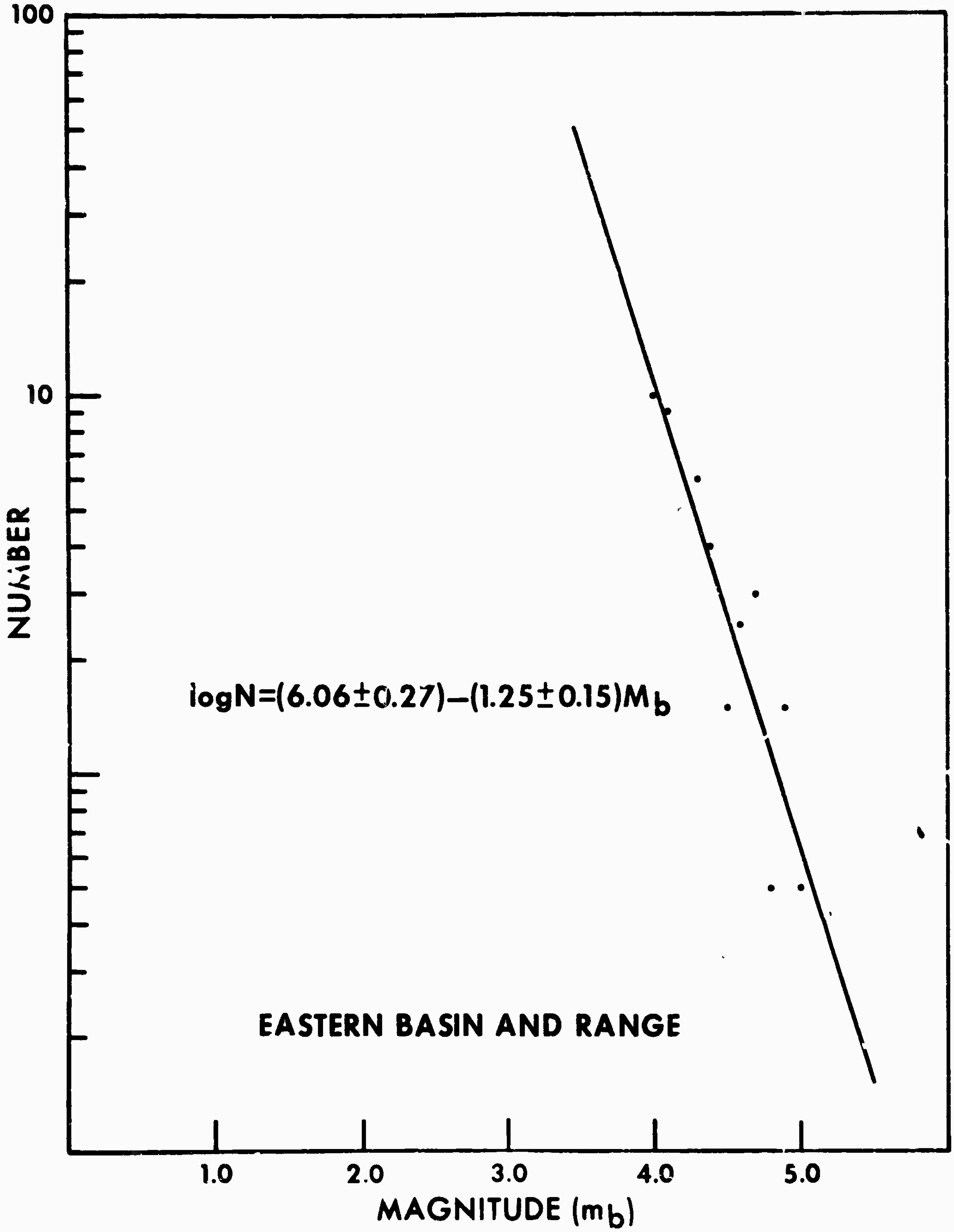


Figure 11. Earthquake Recurrence Curves for the Eastern Basin and Range Based on 1963-64 Data.

not computed, all are above at least m_b = 3.2 and most likely above m_b = 3.4 but below m_b = 4.0. Assuming that the earthquake activity during these two months is representative of the entire year, at least 366 events exceeding magnitude 3.2 were not located in this region in 1963. When these are combined with the reported earthquakes with computed magnitudes between 3.2 and 4.0, the total slightly exceeds the number predicted by the recurrence curve of Figure 11. Special studies of local seismicity in New Mexico and Nevada may be cited as supporting evidence (Mickey, 1964; Sanford, 1965). At the upper end of the scale, Allen, et al. (1965) suggest that the scale may be linear to near the largest earthquakes. It may be expected then that in the range of magnitudes (3.0 to 4.5) of interest in Part II of this report, the linear relationship holds.

If the slope of the recurrence curve is considered uniquely characteristic of earthquake occurrence, then comparisons can be made between areas represented by the curves. On this basis, the ratio of magnitude 5.0 to magnitude 3.0 earthquakes is 0.025 for southern California, 0.011 for northern California, and 0.011 for the eastern Basin and Range. Northern California and the eastern Basin and Range show equal rates of strain release by small earthquakes while southern California shows relatively less strain release by small earthquakes.

However, Tomaki (1963) has warned against the use of recurrence curves for tectonic interpretations. He shows that the slope of the recurrence formula depends on the total number of earthquakes on which the formula is based and the total energy released by them, and never characterizes the mode of earthquake occurrence. The data of this report are insufficient to permit conclusions in this regard.

5. Regional Strain Release Patterns

The relative strain release maps of Figures 12 to 17 are prepared in a manner similar to that described by St. Amand (1956). The displayed values represent what he terms "tectonic flux." Computation is based on the magnitude-energy relation (Richter, 1957, p. 365),

$$\log E = 5.8 + 2.4\ m_b.$$

The ratio of the square root of the energy computed in this manner to the square root of the energy of a magnitude 4.0 earthquake is obtained according to the relation,

$$\log Q_{4.0}^{1/2} = 1.2\ (m_b - 4.0).$$

A fiducial magnitude of 4.0 permits convenient contouring and is the lowest magnitude for which reasonably consistent data are available over the entire region.

To show "tectonic flux" per unit area, a spatial unit of 2,500 km^2 was selected. St. Amand (1956) and Riznichinko (1959) suggest a unit area of about 10,000 km^2 for regional studies.

Niazi (1964) used a unit area ranging between 360 km^2 and 388 km^2 for detailed studies in northern California and western Nevada. Allen, et al. (1965) used 72 km^2 for detailed studies in southern California. The 2,500 km^2 area selected for this study is not entirely arbitrary. It exceeds the limits of the error in epicenter location as well as the total area over which it is expected that strain is released for the largest earthquake of the data sample. Accordingly, no smoothing of the data is required. It is, on the other hand, small enough to allow some detail. The temporal unit is one year.

The "tectonic flux" of each unit area is then determined from

$$\sum Q_{4.0}^{1/2}$$

where the summation extends over all earthquakes in the block. The quantity so determined is plotted in the center of each block and is represented by contours. The contours displayed on Figures 12 to 17 represent the "tectonic flux" by a progression in which each contour above 5.0 has a value twice the preceding smaller one. Contours have been drawn for every area in which earthquakes were located. This procedure results in a number of isolated contours in which the "tectonic flux"

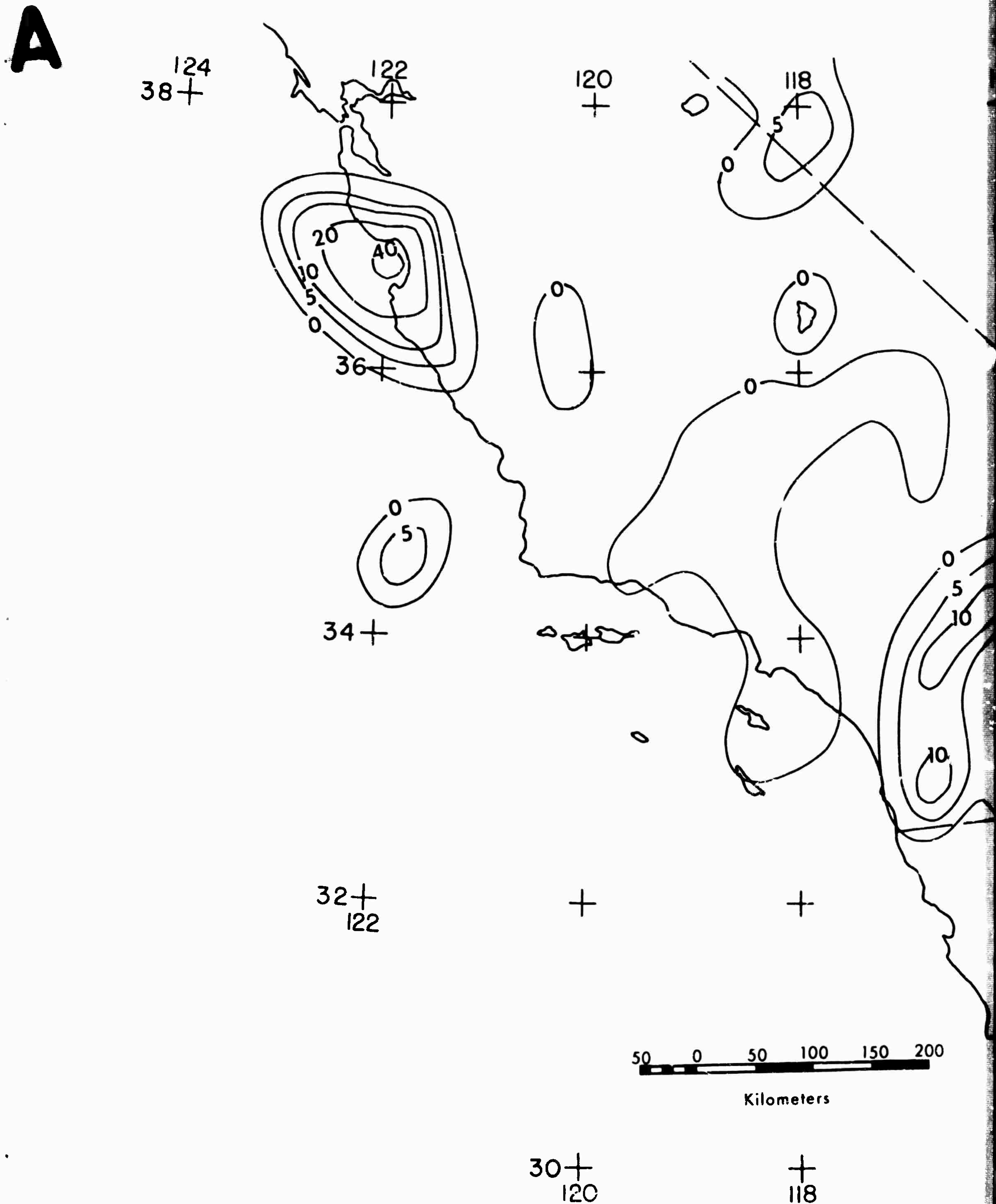
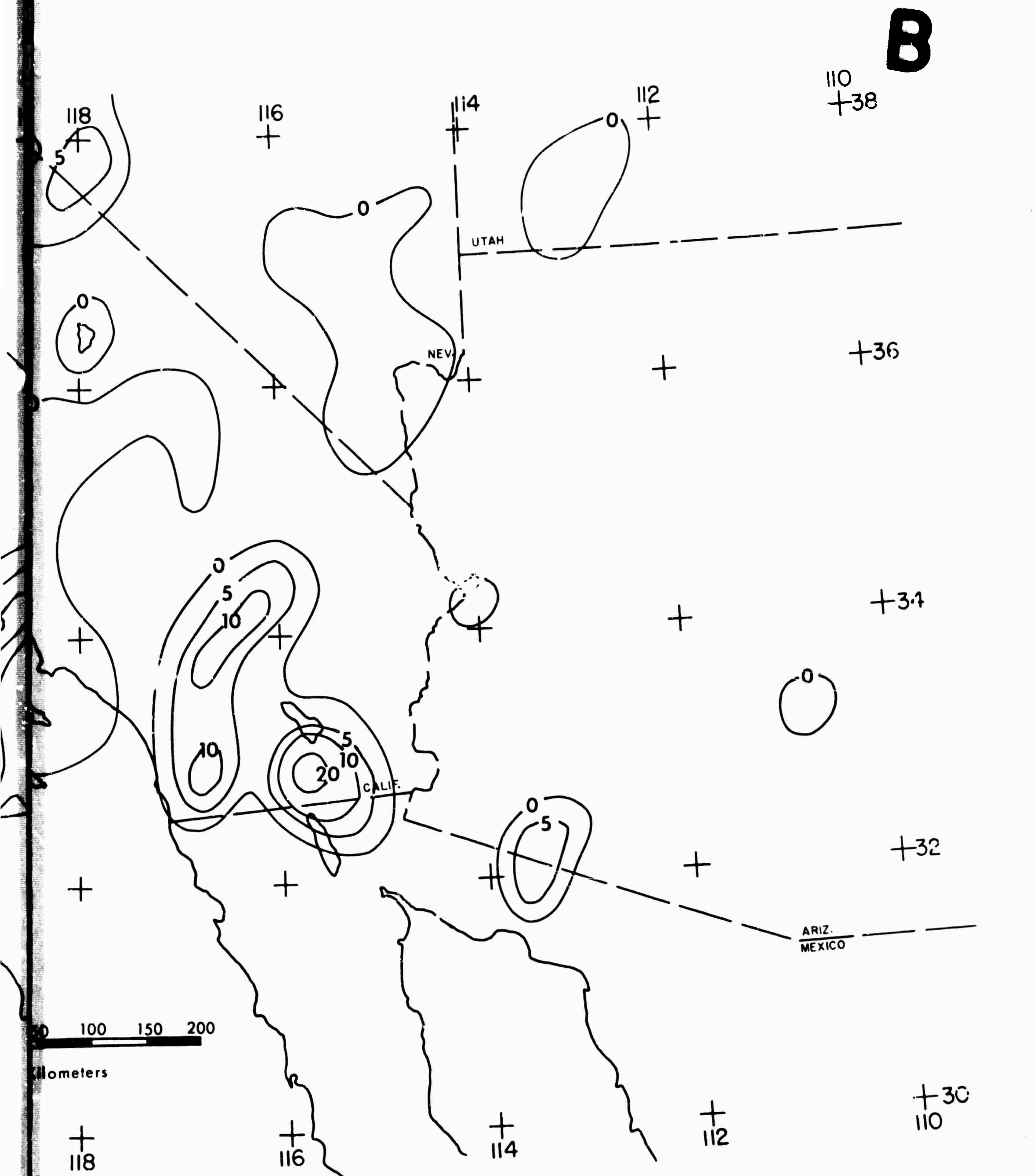


Figure 12. Tectonic Flux for Region



on ... Tectonic Flux for Region 1 During 1963-64.

is greater than zero but does not reach 5.0, the value of the next higher contour. These small values show the effect of one to a few earthquakes whose magnitudes are near or lower than the fiducial magnitude.

The representation of seismicity presented in Figures 12 through 17 provides information about the variation and level of seismic activity in the United States. As has been stated earlier, these must be treated as transient features. However, they assume greater significance when comparisons are made with other seismicity studies.

The high level of activity in southern California centered at 33°N-115°W (see Figure 12) correlates well with similarly high activity displayed by Allen, et al. (1965) based on a 29 year data sample covering the period January 1, 1935 to January 1, 1963. The present data suggest that this high level of activity continued to January 1, 1965. The "tectonic flux" values are the reflection of a large number of earthquakes along the northern extension of the Imperial Fault whose magnitudes were between 4.0 and 5.0. In contrast, the level of activity near the southern extension of the Whitewolf-Kern Canyon Fault is relatively lower than would be expected from comparison with their study. Allen, et al. (1965) point out that the strain

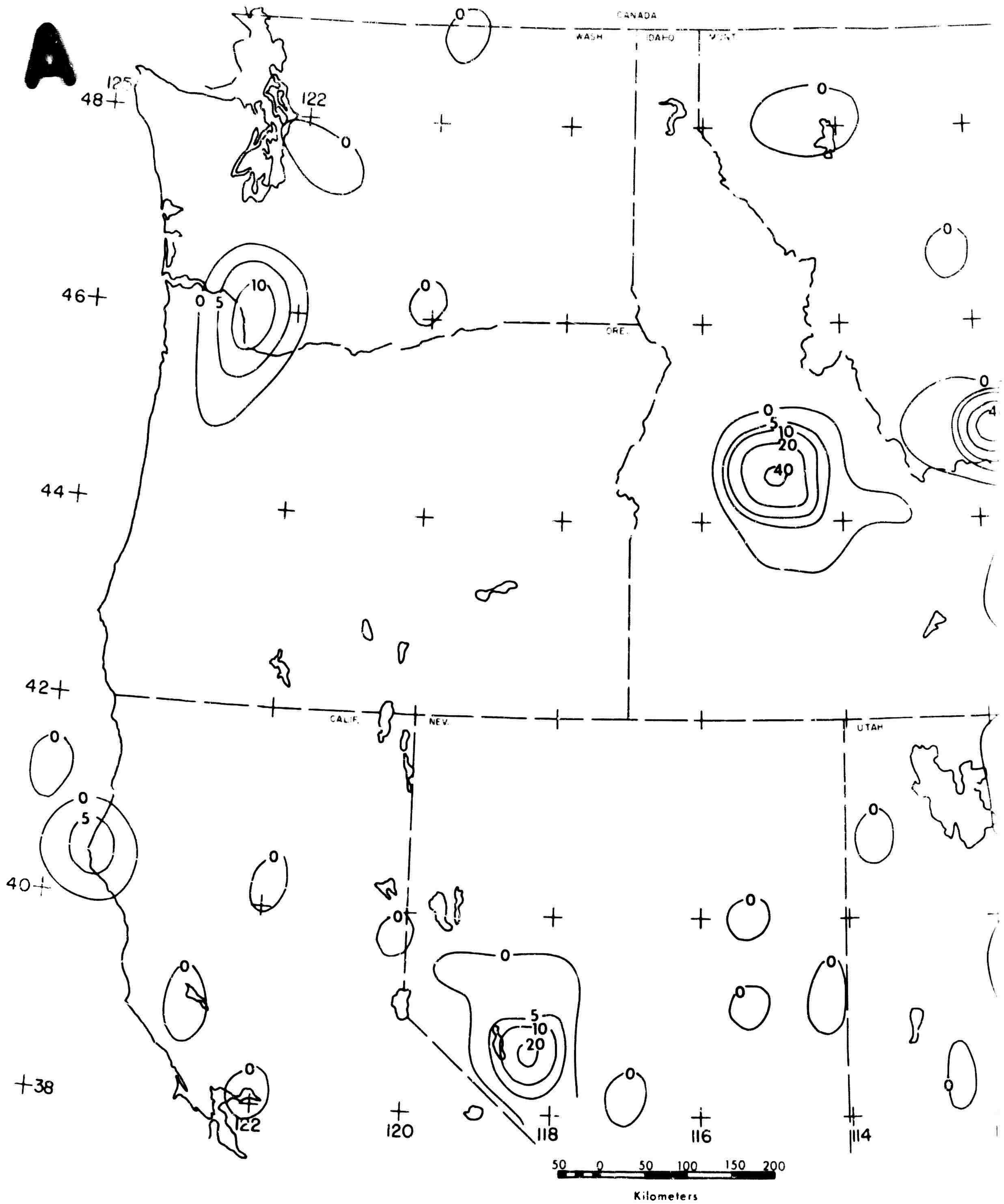


Figure 13. Tectonic Flux for Region 2 During 1963-64.

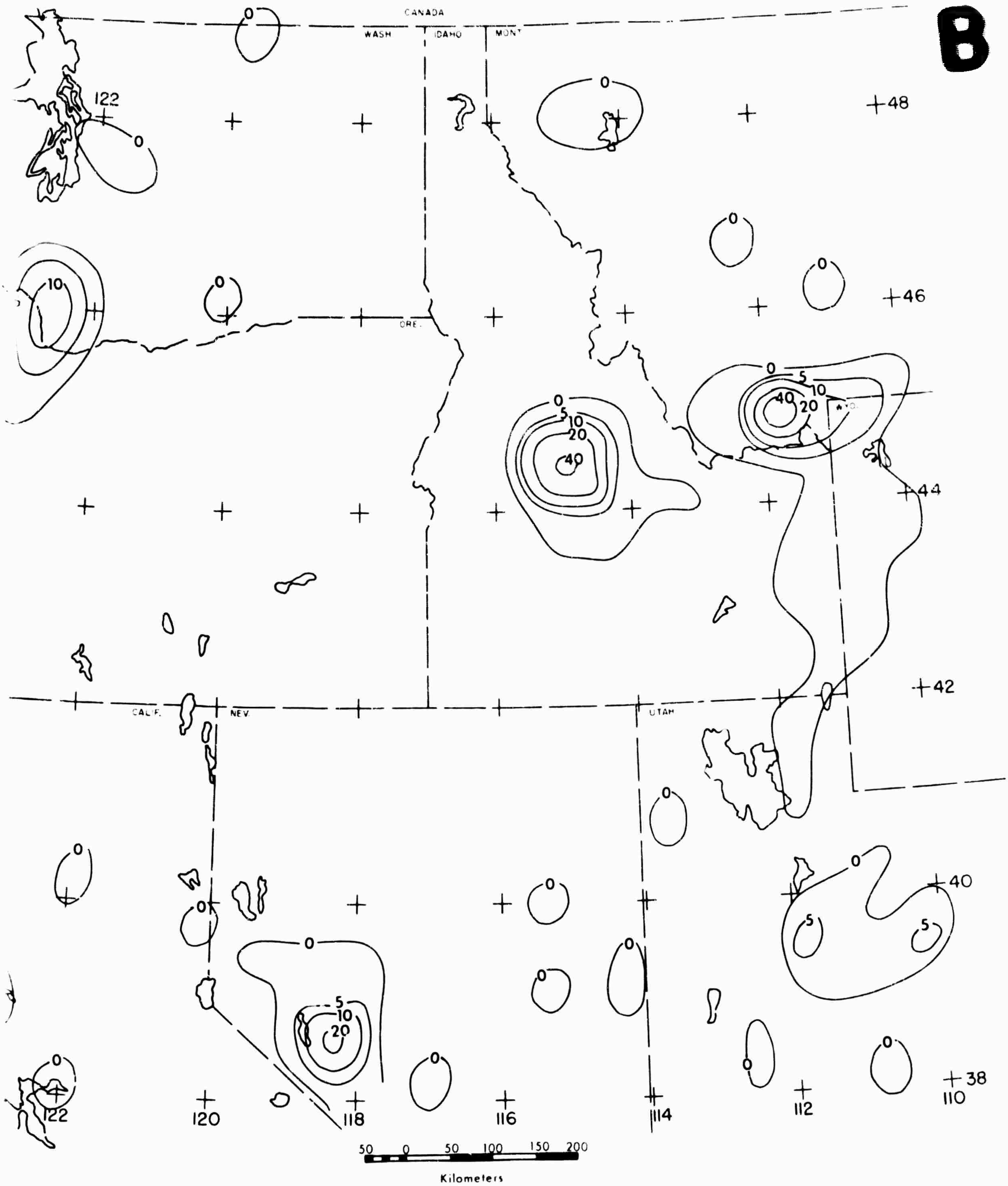


Figure 13. Tectonic Flux for Region 2 During 1963-64.

release pattern in southern California is a result of the occurrence of large earthquakes and is not significantly altered by smaller events. In view of this, and considering the frequency-magnitude relationship, contrasts in the level of activity in any area may be expected when only a small sample of data is considered.

The areas of high activity centered at about 37°N-122°W and at 41°N-124°W, (Figures 12 and 13), correlate well with areas of continued high activity from 1956 through 1960 (Niazi, 1964). This close yearly correlation suggests continuous earthquake activity in these two areas for a long period of time.

In contrast to this suggested continuous activity, the area of high tectonic flux in southwestern Nevada (see Figures 12 and 13) reflects apparent intermittent earthquake occurrences. Niazi (1964) found similar activity in this area due to a series of shocks which occurred within a 40 day period following January 18, 1959. The high tectonic flux shown on Figures 12 and 13 is primarily due to a series of events which occurred during the 36 day period following a magnitude 5.0 event on October 23, 1964, although a series of quakes, mostly having magnitudes less than 4.0, occurred in this area during the 10 day period following March 14, 1964.

Outside of California and western Nevada detailed strain release patterns have not been developed previously. Accordingly, comparisons similar to those which were made in the preceding paragraphs are not possible. However, several observations may be made.

The high tectonic flux displayed on Figure 13 along the Oregon-Washington border, in central Idaho, and southwestern Montana, and on Figure 14 along the Kansas-Nebraska border reflects transient seismic activity. The Oregon-Washington high is somewhat south of the active Puget Sound earthquake region. The southwestern Montana high is similarly south of the more active west-central Montana region, while the central Idaho and Kansas-Nebraska highs are centered in areas which show a history of only minor seismic activity (Heck and Eppley, 1958).

Elsewhere, minor activity is displayed along the Texas-Louisiana border and in southeast Missouri. The former is significant for the absence of historical activity in this area (Heck and Eppley, 1958). The tectonic flux displayed here is due to four earthquakes on April 24, and April 28, 1964. The largest event, having a magnitude of 4.4, occurred on April 28. The southeast Missouri activity is centered in a well known seismic region. Other activity in the eastern United States is due to isolated single earthquakes along the Appalachian Mountains.

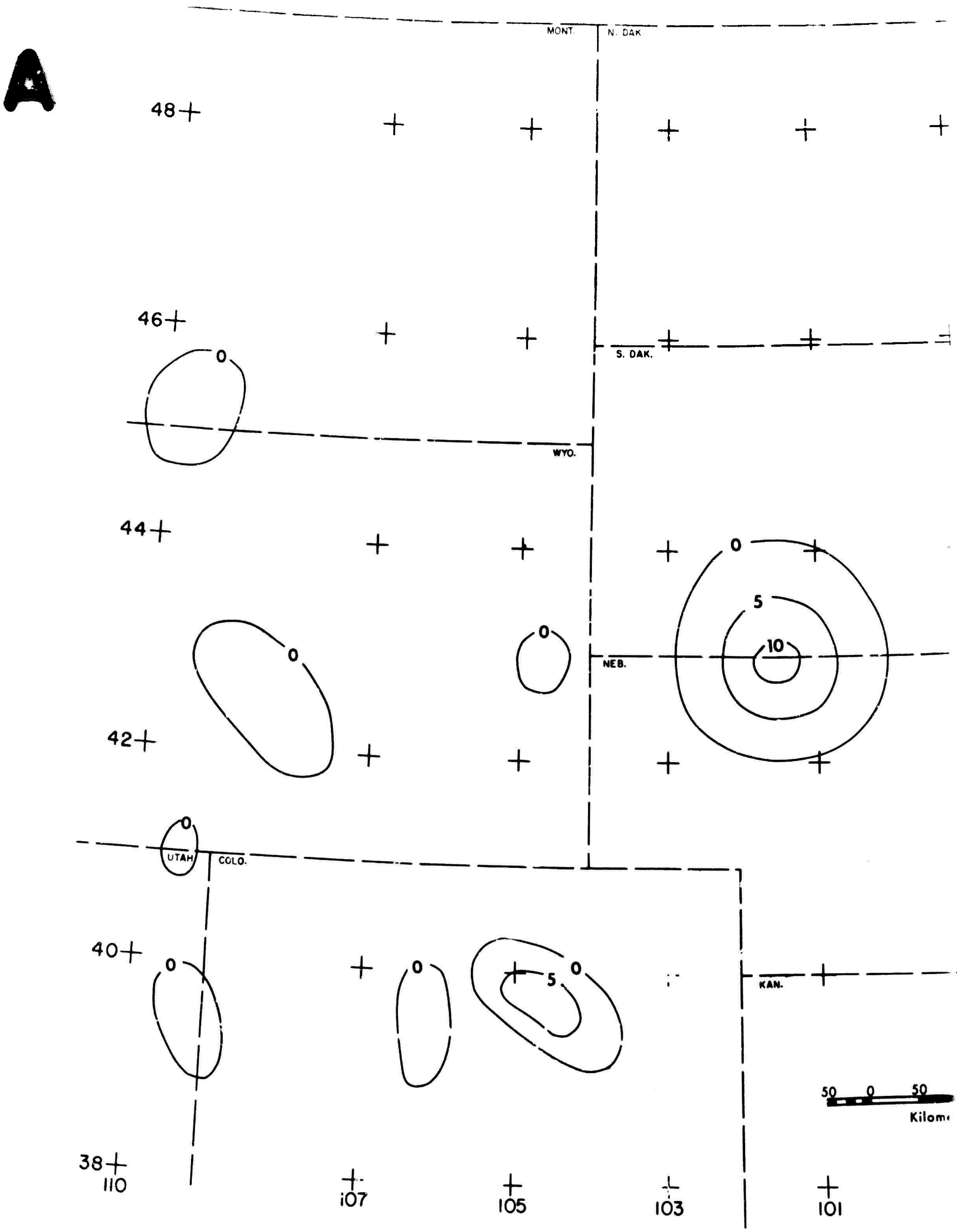


Figure 14. Tectonic Flux for Region 3 During 1963-64.

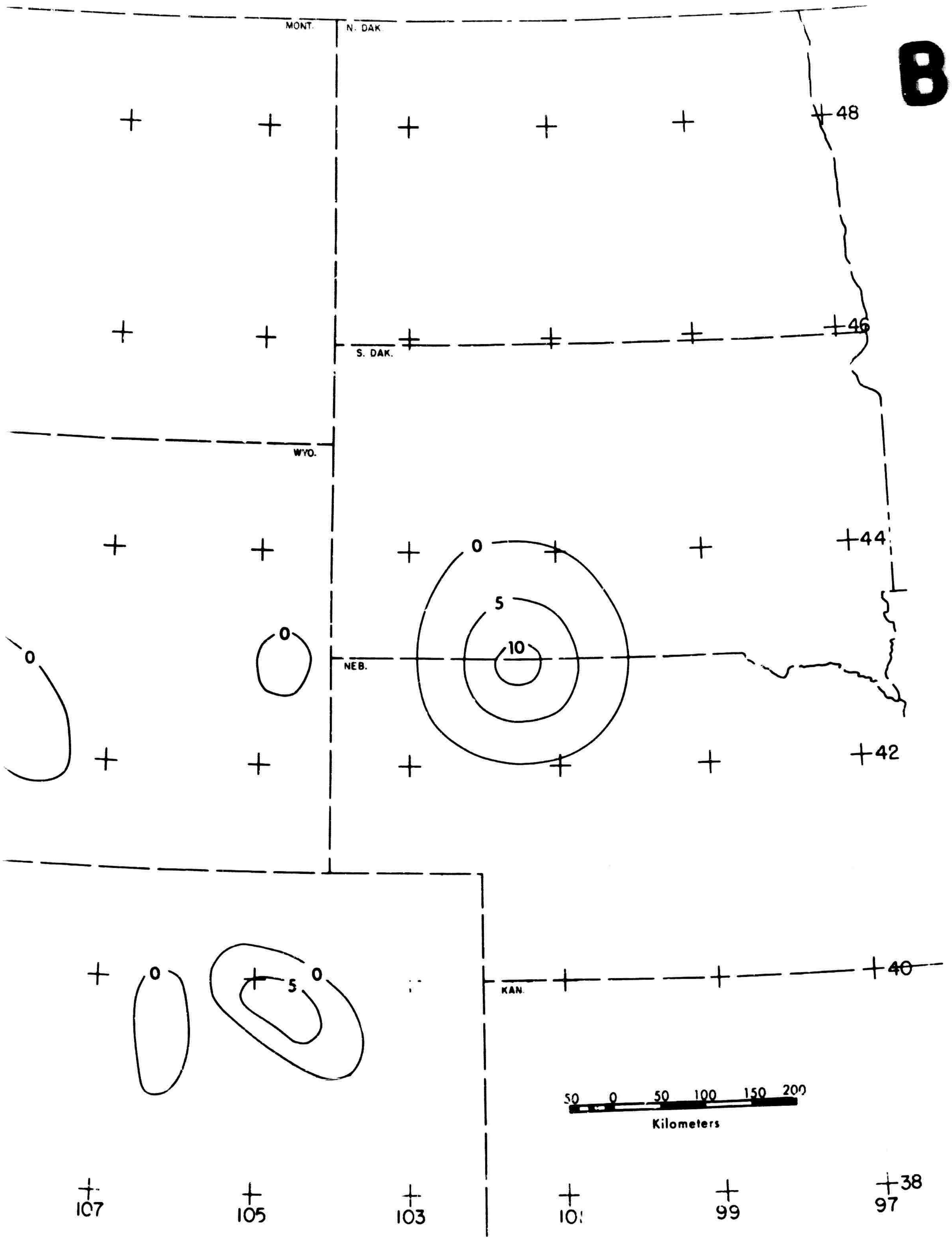


Figure 14 Tectonic Flux for Region 3 During 1963-64.

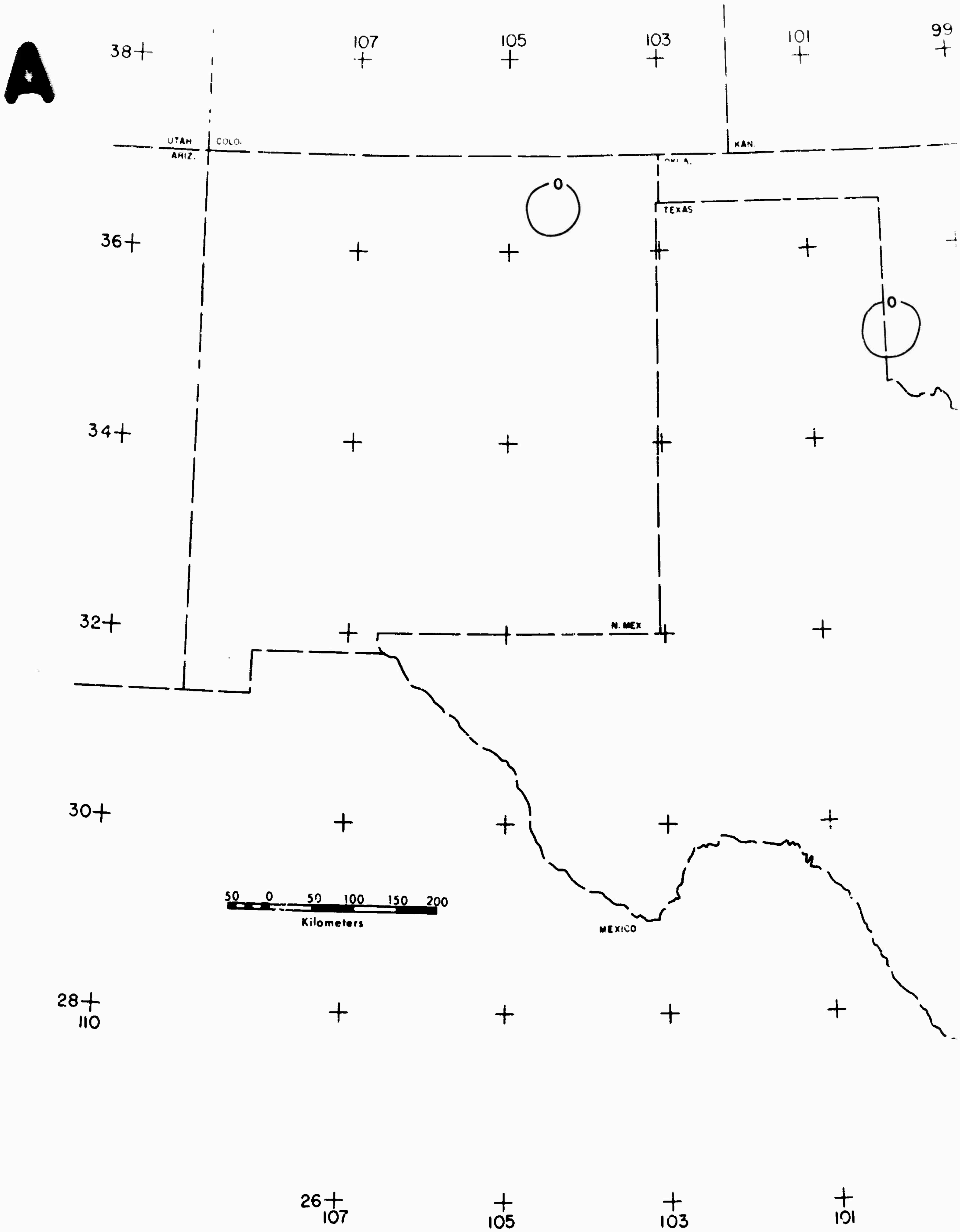


Figure 15. Tectonic Flux for Region 4 During 1963-64.

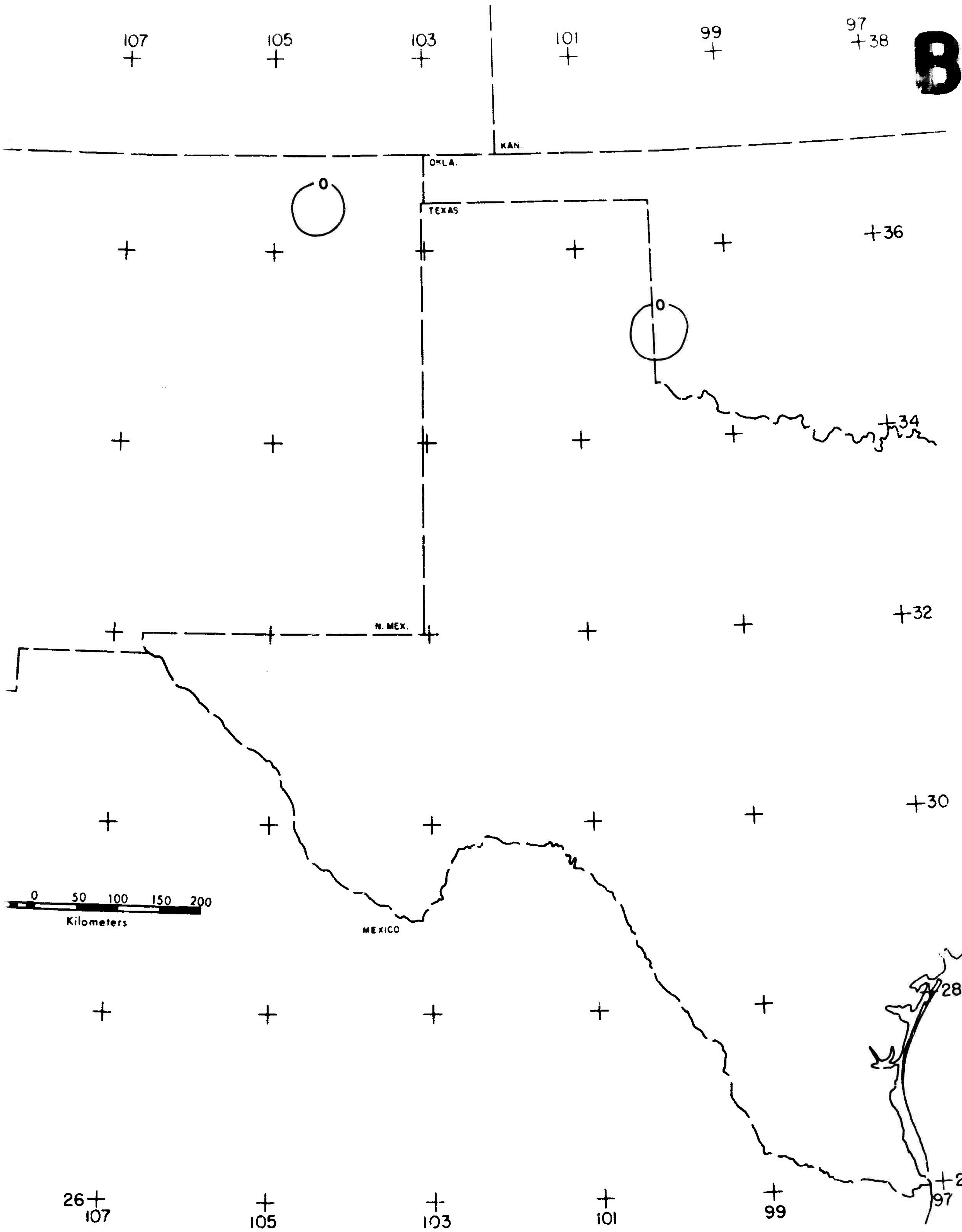


Figure 15. Tectonic Flux for Region 4 During 1963-64.

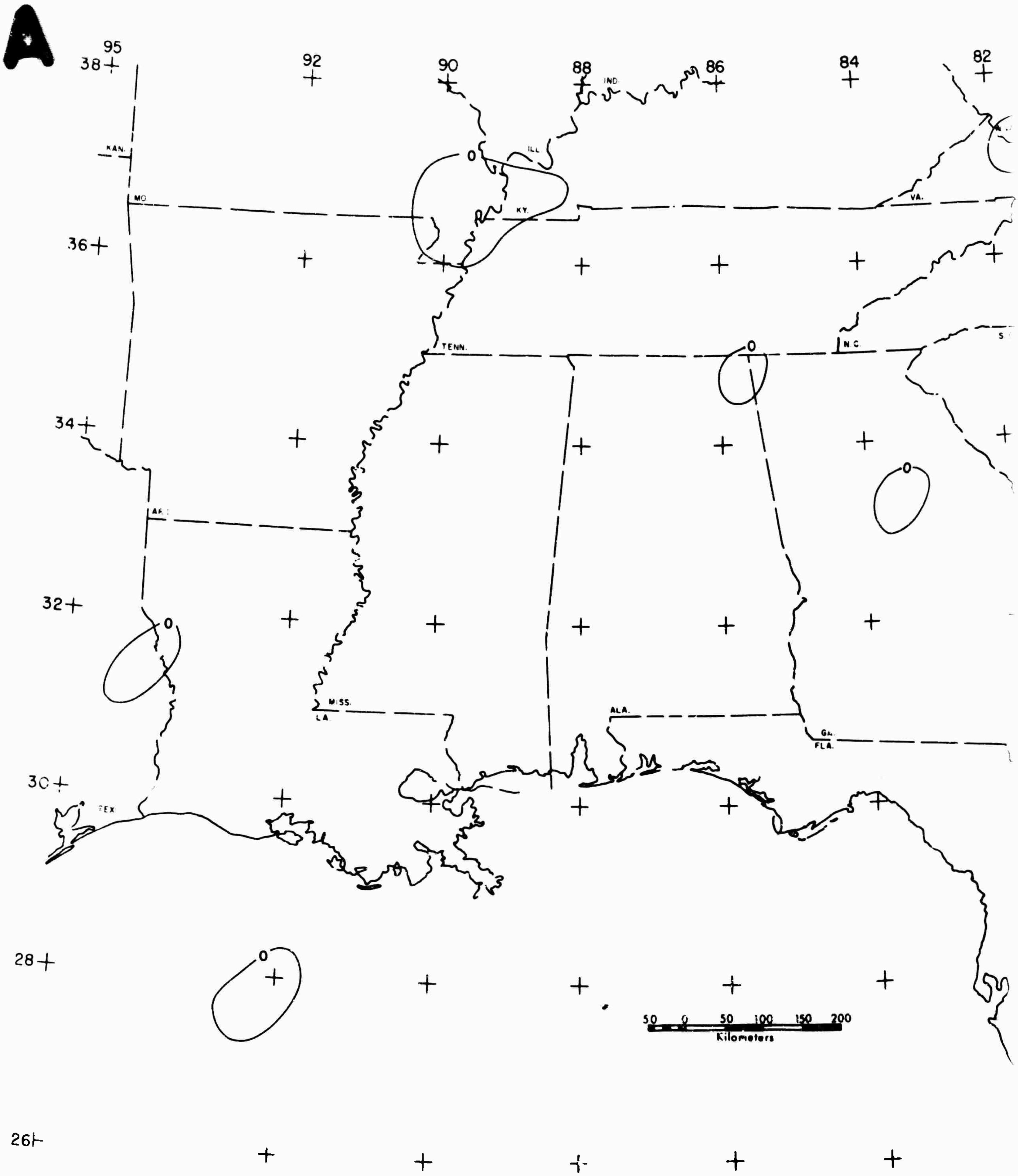


Figure 16. Tectonic Flux for Region 5 During 1963-64.

B

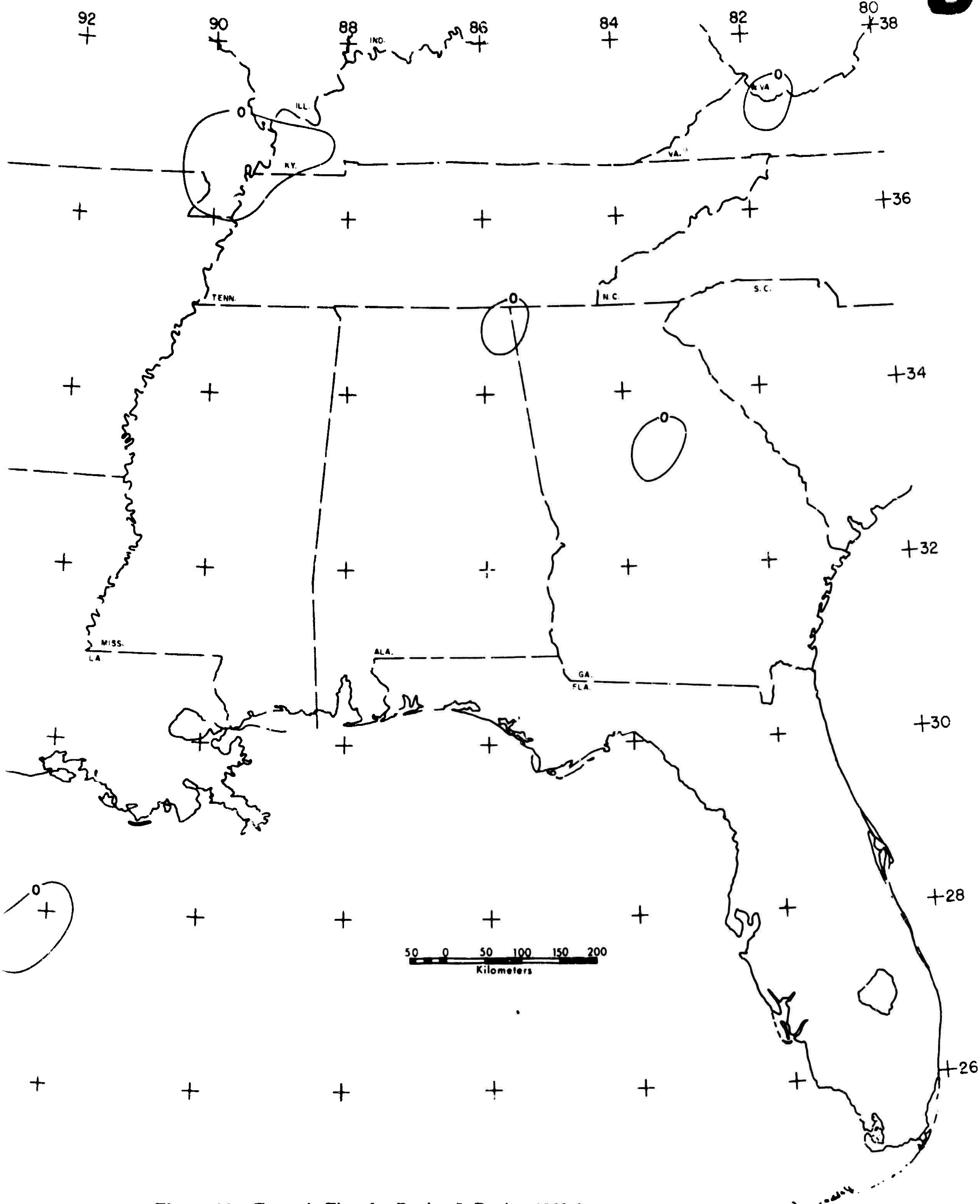


Figure 16. Tectonic Flux for Region 5 During 1963-64.

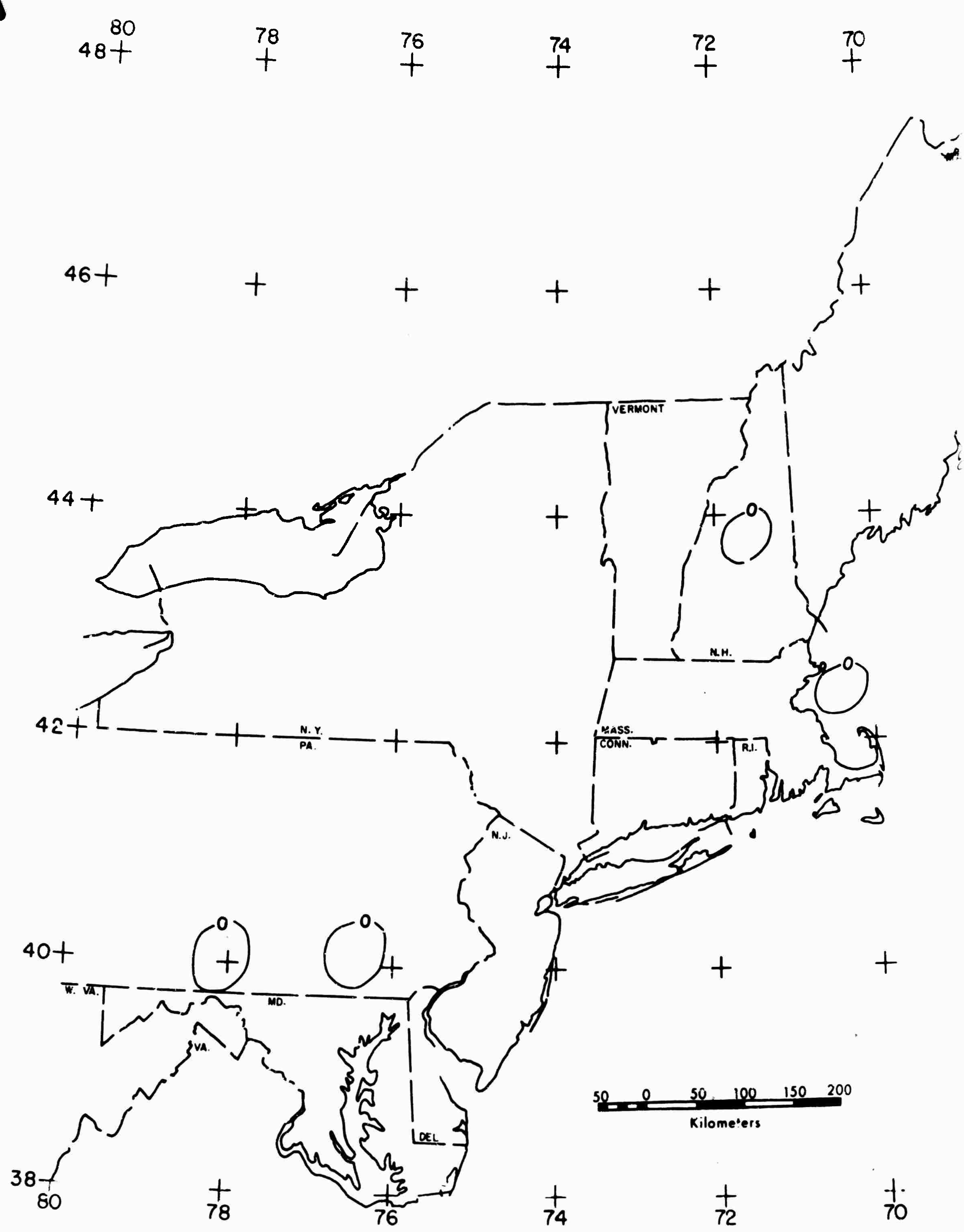


Figure 17. Tectonic Flux for Region 7 During 1963-64.

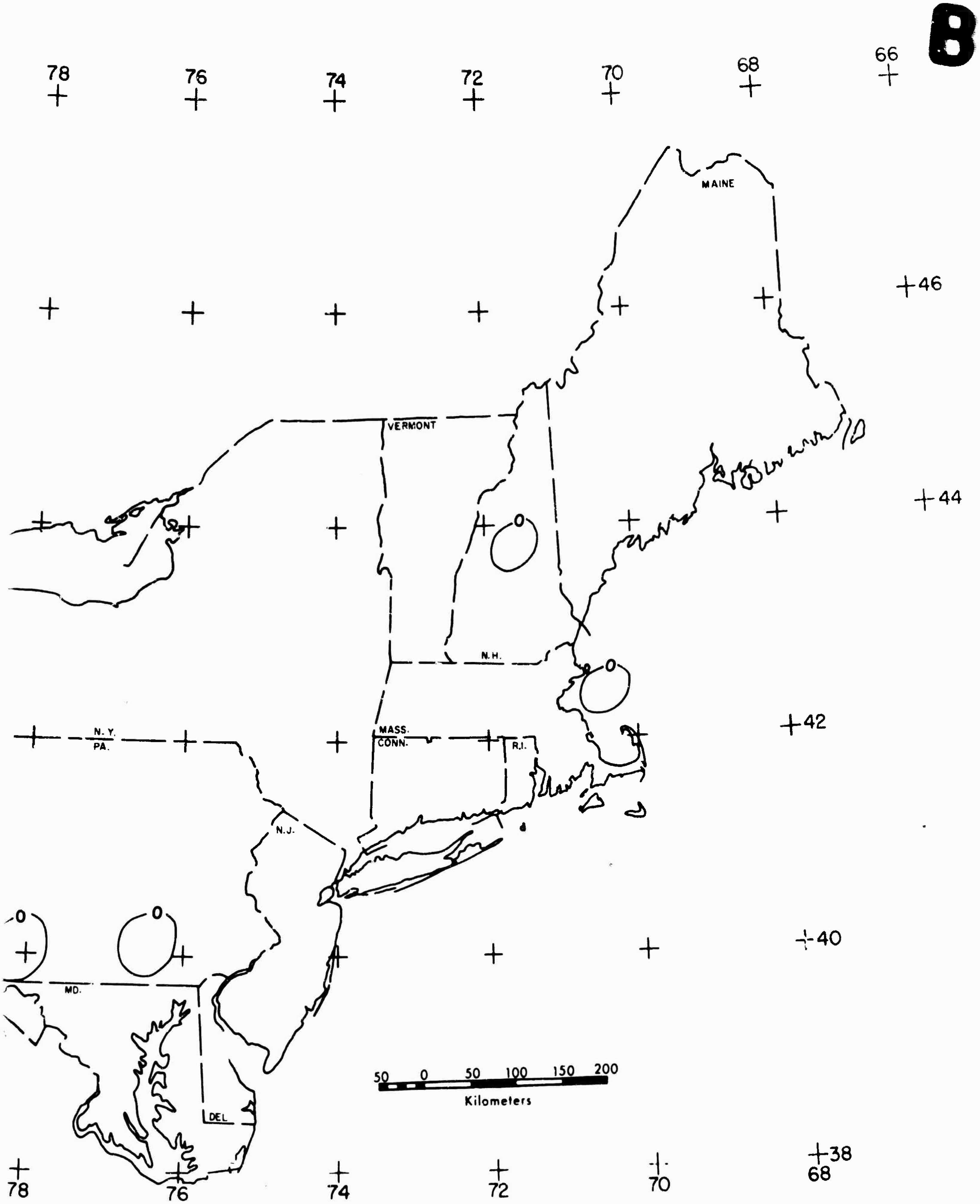


Figure 17. Tectonic Flux for Region 7 During 1963-64.

6. Conclusions

The Coast and Geodetic Survey reported 691 earthquakes in the conterminous United States during 1963-64. Of this total, 90% had epicenters in the western states west of the eastern edge of the Rocky Mountains.

In terms of numbers of earthquakes, the western mountain region displays the greatest activity with the Pacific coast showing relatively fewer earthquakes. However, it is suggested that this is due to incomplete reports of earthquake activity along the Pacific coast during the period covered by the report. East of the Rocky Mountain front the only area of significant activity is the well known seismic area of southeast Missouri.

Depths are often restrained in the hypocenter computation to conform with historical data. Accordingly, the earthquakes reported here do not permit conclusions regarding focal depth. It is observed, however, that all of the earthquakes included in the study probably have focal depths within the earth's crust.

If it is assumed that the slope of the recurrence curves has tectonic implications, the northern California and the eastern Basin and Range show equal rates of strain release by low magnitude earthquakes. Conversely, southern California shows a relatively greater rate of strain release by larger magnitude earthquakes.

The seismic activity shows grouping in both time and space. The degree to which this reflects secular seismic patterns cannot be established from the data of this report alone.

TABLE 1

CHRONOLOGICAL LISTING OF EARTHQUAKES IN THE CONTERMINOUS UNITED STATES DURING 1963-64 WHICH WERE REPORTED ON P.D.E. CARDS

Date	Time GMT	Lat. Deg.	Long. Deg.	Depth km	Mag.
Jan 05 63	21 27 02.7	41.0	126.1	33	*
Jan 06 63	18 07 47.8	44.7	112.0	33	4.0
Jan 13 63	02 39 38.7	32.9	116.5	33	4.1
Jan 20 63	09 24 39.7	44.9	110.9	28	*
Jan 24 63	21 43 13.0	47.5	121.9	33	4.7
Jan 27 63	03 00 38.7	31.6	115.7	33	4.6
Jan 27 63	15 24 46.5	44.3	114.5	31	4.3
Jan 30 63	05 51 00.9	44.9	110.8	33	4.0
Jan 30 63	23 05 09.6	39.8	104.6	33	4.5
Feb 01 63	16 38 58.3	44.2	114.6	33	4.4
Feb 02 63	11 51 41.7	39.0	122.8	33	3.7
Feb 02 63	12 09 36.9	39.0	122.8	33	4.1
Feb 02 63	13 58 18.9	36.8	121.5	16	3.6
Feb 05 63	07 29 00.3	44.3	114.5	33	4.0
Feb 16 63	03 01 40.5	46.2	111.0	33	4.5
Feb 21 63	12 01 19.4	40.4	125.0	33	4.2
Feb 24 63	15 24 56.6	44.9	112.0	33	4.4
Feb 25 63	18 45 15.1	42.8	109.0	33	4.3
Mar 01 63	00 25 57.4	34.8	119.3	16	4.0
Mar 03 63	17 30 13.0	36.7	090.1	18	4.5
Mar 05 63	01 30 38.5	42.5	111.3	33	4.1
Mar 07 63	23 53 25.6	44.8	123.4	33	4.6
Mar 08 63	08 35 49.2	44.8	110.3	33	3.8
Mar 10 63	11 26 03.1	44.9	110.3	33	4.0
Mar 10 63	11 40 28.9	38.4	127.2	33	4.2
Mar 10 63	13 16 55.7	45.4	109.4	33	3.6
Mar 12 63	03 41 21.8	45.3	109.6	33	3.8
Mar 17 63	11 11 36.3	39.2	111.9	33	*
Mar 17 63	22 10 36.2	44.8	110.3	33	3.8
Mar 20 63	11 38 33.1	44.9	110.7	33	4.1
Mar 20 63	12 32 26.0	44.6	110.5	33	4.0
Mar 21 63	16 09 48.3	44.9	110.7	33	3.9
Mar 22 63	04 34 43.3	44.7	110.7	33	4.1
Mar 23 63	12 21 43.3	45.0	111.4	34	3.8
Mar 25 63	09 28 44.1	36.0	114.9	17	4.3
Mar 25 63	17 43 55.4	45.0	111.3	33	4.1
Mar 27 63	07 22 08.9	44.3	110.6	33	4.2

Table 1 (Con't)

Mar 27 63	15	15	43.0	45.3	109.8	33	4.0
Apr 01 63	20	37	09.1	36.1	114.8	33	4.3
Apr 02 63	09	40	44.9	36.2	114.9	33	4.1
Apr 02 63	13	40	12.7	44.8	110.7	33	4.1
Apr 02 63	15	29	42.6	44.7	110.5	33	4.0
Apr 03 63	09	35	03.3	45.0	109.9	33	4.0
Apr 04 63	15	36	27.1	42.2	111.2	33	4.0
Apr 06 63	07	51	04.2	36.4	089.8	18	4.2
Apr 06 63	08	12	24.0	36.4	089.7	18	4.3
Apr 06 63	20	18	19.3	40.7	128.3	33	4.2
Apr 08 63	00	03	59.1	39.6	104.9	33	4.4
Apr 16 63	05	34	34.6	44.8	110.4	33	3.7
Apr 18 63	14	59	11.7	45.0	110.9	33	3.9
Apr 19 63	03	21	11.6	35.7	118.1	33	3.8
Apr 19 63	06	19	16.8	31.6	115.7	14	4.3
Apr 24 63	13	33	06.6	39.5	110.0	42	4.6
Apr 24 63	22	29	35.7	39.7	104.8	33	4.1
Apr 27 63	04	53	50.9	44.8	110.4	33	4.4
Apr 27 63	13	39	34.6	45.0	111.4	33	4.0
May 02 63	01	09	21.7	36.7	089.4	18	4.5
May 03 63	16	32	56.0	45.0	111.2	33	3.6
May 04 63	12	29	43.3	44.3	128.7	33	4.2
May 06 63	05	09	00.1	39.6	110.0	33	3.8
May 07 63	07	07	45.1	36.7	121.8	14	*
May 11 63	02	55	58.4	45.2	110.0	33	3.9
May 11 63	03	01	00.1	44.9	110.8	33	3.9
May 18 63	20	58	52.5	35.7	115.1	33	4.4
May 19 63	08	10	21.4	44.4	111.1	33	*
May 22 63	22	40	59.1	37.0	123.1	14	4.8
May 23 63	06	36	32.0	32.9	115.5	14	4.6
May 23 63	09	05	59.3	31.9	115.9	14	4.6
May 23 63	09	06	02.6	32.8	115.6	14	4.6
May 23 63	15	53	00.2	32.5	115.3	14	4.8
May 25 63	10	44	38.1	39.8	104.7	33	4.1
May 28 63	16	29	11.9	44.3	114.8	33	3.7
May 31 63	01	21	49.8	45.0	111.1	33	*
May 31 63	11	37	56.2	44.9	111.4	33	3.8
Jun 05 63	00	13	50.6	39.3	104.0	33	4.4
Jun 06 63	08	05	36.3	36.5	104.3	33	3.8
Jun 07 63	12	04	39.7	38.0	122.0	14	4.3
Jun 08 63	08	51	56.2	40.6	124.3	33	4.1
Jun 11 63	15	23	42.3	31.8	116.2	33	5.2
Jun 12 63	22	15	15.3	31.6	116.3	33	*
Jun 15 63	13	15	52.6	45.0	110.8	33	4.1
Jun 19 63	08	38	47.6	37.9	112.5	36	4.2
Jun 20 63	14	59	42.6	30.2	114.1	14	4.5
Jun 25 63	15	51	49.0	44.0	110.0	33	4.2
Jun 29 63	08	09	27.6	40.3	126.9	33	4.2

Table 1 (Con't)

Jul 02 63	06 30 13.8	30.7	114.2	33	3.9
Jul 02 63	08 02 54.1	39.8	104.7	15	4.6
Jul 02 63	12 34 34.0	42.9	126.2	33	4.1
Jul 04 63	05 50 49.5	43.7	126.4	33	4.4
Jul 07 63	19 20 42.3	39.6	111.9	33	4.9
Jul 08 63	04 19 08.4	40.8	125.8	33	4.7
Jul 08 63	23 51 42.9	37.0	090.5	25	4.1
Jul 09 63	15 20 46.3	39.8	111.8	33	3.6
Jul 09 63	20 25 28.8	40.1	111.3	33	4.1
Jul 10 63	12 07 35.3	39.7	112.0	33	3.4
Jul 10 63	18 32 50.6	39.9	111.4	33	4.2
Jul 16 63	09 18 21.3	34.1	116.1	14	4.0
Jul 17 63	20 44 32.0	34.0	116.0	14	4.3
Jul 17 63	23 05 42.5	34.1	116.1	14	4.2
Jul 18 63	04 01 16.3	37.2	115.6	25	3.9
Jul 18 63	06 33 23.8	37.1	115.5	25	3.9
Jul 18 63	10 40 30.4	34.1	116.1	14	4.3
Jul 18 63	19 37 43.7	34.1	116.1	14	4.4
Jul 18 63	23 11 05.5	34.1	116.2	14	3.9
Jul 19 63	08 33 32.7	34.1	116.1	14	4.2
Jul 19 63	15 54 55.4	34.1	116.1	14	4.4
Jul 19 63	19 26 32.6	45.0	110.4	33	3.5
Jul 19 63	20 56 43.2	45.1	110.0	33	3.4
Jul 20 63	10 41 02.5	45.1	111.3	33	3.4
Jul 20 63	19 13 05.9	37.1	115.6	25	4.1
Jul 24 63	10 57 46.9	44.9	111.1	33	3.3
Jul 26 63	07 33 42.2	33.5	117.8	14	4.6
Jul 27 63	06 27 03.0	43.9	128.3	33	4.5
Jul 30 63	06 34 54.8	34.0	116.3	14	4.7
Jul 30 63	22 45 51.8	33.7	116.4	33	4.3
Aug 01 63	04 01 04.6	40.0	115.6	33	3.8
Aug 01 63	05 00 17.3	39.3	109.1	33	3.7
Aug 02 63	09 45 41.9	43.4	114.5	50	3.6
Aug 02 63	22 17 25.6	40.5	125.1	33	5.1
Aug 03 63	00 37 50.3	37.0	088.8	18	3.6
Aug 03 63	01 23 16.7	44.9	115.4	33	4.0
Aug 06 63	05 20 32.0	45.1	111.4	33	3.7
Aug 06 63	23 38 46.3	33.8	116.7	14	5.0
Aug 08 63	09 54 42.8	45.2	111.5	33	3.6
Aug 08 63	23 53 20.8	44.9	110.9	33	4.0
Aug 14 63	12 30 06.0	41.5	112.2	33	3.7
Aug 15 63	21 02 33.8	36.1	121.1	33	4.0
Aug 15 63	21 21 33.1	35.9	121.1	33	4.0
Aug 16 63	03 21 08.7	39.7	112.1	33	3.4
Aug 16 63	07 01 03.7	41.5	112.2	33	3.6
Aug 17 63	05 09 11.1	41.4	112.2	33	3.5
Aug 17 63	10 23 15.5	40.4	110.7	33	3.5

Table 1 (Con't)

Aug 19 63	09 38 59.9	40.9	126.0	33	4.1
Aug 22 63	04 33 54.2	34.1	116.2	14	4.4
Aug 22 63	09 27 09.3	42.0	126.2	33	5.6
Aug 22 63	12 13 11.4	33.7	118.0	14	4.3
Aug 24 63	03 15 49.8	40.8	112.0	33	3.5
Aug 24 63	10 49 08.7	36.0	117.6	25	3.7
Aug 24 63	13 28 20.3	34.2	116.4	14	3.3
Aug 24 63	20 47 36.5	31.4	11[illegible].4	14	4.5
Aug 27 63	01 20 54.6	31.6	116.2	14	4.4
Aug 28 63	00 13 12.9	40.9	111.9	33	3.4
Aug 31 63	16 31 12.5	36.6	121.8	15	4.7
Sep 02 63	03 46 14.8	49.5	128.3	33	3.7
Sep 02 63	13 20 00.1	29.1	109.3	33	3.7
Sep 02 63	13 30 03.8	50.4	129.1	33	4.4
Sep 02 63	17 40 14.9	39.6	110.2	33	4.1
Sep 04 63	12 41 16.6	43.9	128.6	33	4.0
Sep 06 63	22 19 35.2	44.3	114.7	33	4.1
Sep 09 63	10 45 19.7	44.4	114.6	33	4.1
Sep 09 63	18 50 46.9	43.9	113.3	33	3.3
Sep 09 63	19 07 19.0	44.3	114.6	33	3.8
Sep 09 63	19 10 37.1	44.4	114.8	33	4.1
Sep 10 63	02 17 11.2	44.3	114.7	33	4.3
Sep 10 63	03 33 25.0	44.4	114.7	33	4.1
Sep 11 63	00 12 29.6	44.3	114.7	33	4.4
Sep 11 63	02 08 44.7	44.3	114.7	15	4.9
Sep 11 63	02 31 42.0	44.4	114.7	33	4.2
Sep 11 63	03 45 35.6	44.4	114.8	33	4.1
Sep 11 63	03 55 39.6	44.4	114.8	33	*
Sep 11 63	06 04 28.3	38.9	118.1	33	3.7
Sep 11 63	09 42 06.9	44.3	114.8	33	4.0
Sep 11 63	11 59 41.2	33.2	110.7	33	4.1
Sep 11 63	12 29 30.9	44.3	114.7	33	3.8
Sep 11 63	18 21 53.4	44.2	114.8	33	3.8
Sep 11 63	18 24 30.5	44.3	114.7	33	4.1
Sep 11 63	20 34 51.5	44.5	114.8	33	3.5
Sep 11 63	23 40 51.7	40.8	112.0	33	3.8
Sep 12 63	06 23 51.7	44.2	114.8	33	4.4
Sep 12 63	06 53 00.9	44.2	114.5	33	4.1
Sep 12 63	08 01 23.2	44.4	114.7	33	4.3
Sep 12 63	09 01 11.4	44.3	114.8	33	3.6
Sep 12 63	09 19 07.0	44.3	115.0	33	3.7
Sep 12 63	11 16 48.9	44.4	114.7	33	4.3
Sep 12 63	12 28 25.4	44.4	114.8	33	4.2
Sep 12 63	20 15 08.4	44.4	114.8	33	4.0
Sep 13 63	13 43 13.7	45.0	111.6	33	3.4
Sep 14 63	03 51 13.6	33.3	118.6	14	4.8

Table 1 (Con't)

Sep 14 63	05 04 11.4	44.3	115.1	33	3.8
Sep 14 63	05 07 15.7	44.4	114.7	33	3.6
Sep 14 63	12 28 14.5	35.6	118.1	14	4.2
Sep 14 63	15 58 03.8	44.2	114.8	33	4.3
Sep 14 63	16 06 49.3	44.3	114.7	33	3.9
Sep 14 63	16 25 13.2	44.3	114.7	33	4.3
Sep 14 63	16 39 43.4	44.4	114.7	33	4.0
Sep 14 63	16 55 43.4	44.4	114.7	33	3.9
Sep 14 63	17 16 36.9	44.2	114.8	33	3.8
Sep 14 63	17 [illegible] 09.6	44.5	114.7	33	4.0
Sep 14 63	18 48 58.4	44.3	114.7	33	3.8
Sep 14 63	19 46 15.8	36.7	121.8	15	5.4
Sep 14 63	20 28 08.5	36.7	122.0	15	4.3
Sep 15 63	05 35 00.2	44.3	114.8	33	3.9
Sep 15 63	10 48 03.4	35.7	117.8	15	3.4
Sep 15 63	16 51 04.0	44.4	114.8	33	4.1
Sep 15 63	19 17 11.3	44.2	114.8	33	3.7
Sep 16 63	12 06 15.9	44.2	114.7	33	4.2
Sep 16 63	17 15 34.5	43.2	126.8	33	4.7
Sep 17 63	05 36 17.1	44.3	114.8	33	4.1
Sep 17 63	12 22 56.8	44.4	114.7	33	3.6
Sep 18 63	00 16 07.8	44.3	114.8	33	3.7
Sep 18 63	04 45 08.3	44.9	111.6	33	3.1
Sep 18 63	21 03 52.5	44.4	114.8	33	3.8
Sep 19 63	03 02 07.8	44.5	114.7	33	3.9
Sep 19 63	10 59 59.5	44.3	114.9	33	3.4
Sep 20 63	11 09 38.8	44.3	114.8	33	3.8
Sep 20 63	11 41 22.0	44.4	114.7	33	3.7
Sep 21 63	04 32 43.5	37.2	121.7	14	4.2
Sep 21 63	09 58 59.5	44.3	114.8	33	3.9
Sep 21 63	12 29 25.8	43.7	114.7	33	3.5
Sep 22 63	00 50 37.8	44.3	114.8	33	4.2
Sep 22 63	00 56 13.7	44.5	114.7	33	4.2
Sep 22 63	04 37 15.3	43.3	111.4	33	3.6
Sep 22 63	08 58 10.5	43.3	111.5	33	3.9
Sep 22 63	09 56 42.8	43.4	111.5	33	3.7
Sep 22 63	14 55 03.3	44.4	114.9	33	4.1
Sep 22 63	15 41 21.0	44.4	114.8	33	4.0
Sep 22 63	15 58 06.1	41.9	126.7	33	4.3
Sep 22 63	17 06 07.0	43.3	111.2	33	3.9
Sep 22 63	21 13 35.6	44.3	114.6	33	3.9
Sep 22 63	21 30 56.7	43.3	111.6	33	3.4
Sep 22 63	21 32 17.1	43.2	111.3	33	3.4
Sep 22 63	22 36 23.6	42.0	126.5	33	4.3
Sep 23 63	01 30 32.8	43.2	111.2	33	3.5
Sep 23 63	10 21 05.7	44.4	114.8	33	3.6
Sep 23 63	12 17 10.5	44.4	114.8	33	3.9

Table 1 (Con't)

Sep 23 63	14 41 51.5	33.7	117.0	14	4.3
Sep 23 63	23 27 10.5	43.3	111.5	33	3.7
Sep 24 63	06 31 50.5	44.8	111.0	33	3.6
Sep 24 63	06 35 52.1	44.9	111.0	33	4.7
Sep 24 63	17 05 27.9	43.2	111.1	33	3.5
Sep 27 63	16 46 12.2	32.6	115.5	33	3.5
Sep 28 63	19 08 02.8	43.3	111.3	33	3.7
Sep 29 63	05 58 23.3	43.5	111.3	33	3.6
Sep 29 63	06 05 32.1	43.3	111.5	33	3.6
Sep 30 63	09 17 42.2	38.0	111.0	33	4.5
Oct 03 63	18 42 22.3	39.2	115.2	33	3.7
Oct 04 63	17 49 11.7	30.2	114.3	14	4.8
Oct 04 63	17 58 19.4	30.6	113.9	14	4.1
Oct 04 63	21 15 24.6	30.0	114.3	14	4.3
Oct 04 63	21 19 11.5	30.1	114.3	14	5.0
Oct 05 63	04 22 54.1	43.7	127.1	16	4.2
Oct 05 63	11 55 56.7	47.4	128.6	33	4.3
Oct 07 63	21 30 30.0	44.8	114.4	33	3.5
Oct 10 63	03 15 15.2	47.6	127.1	33	3.9
Oct 10 63	14 59 52.3	39.8	078.2	15	3.6
Oct 11 63	23 09 53.2	43.4	111.1	33	4.3
Oct 12 63	06 58 26.9	43.4	111.1	33	3.9
Oct 12 63	21 59 02.4	43.1	111.2	33	3.9
Oct 12 63	22 34 01.6	43.1	111.3	33	3.9
Oct 13 63	17 55 47.7	43.2	111.3	33	3.7
Oct 14 63	08 31 23.3	42.2	108.3	33	4.5
Oct 16 63	15 31 00.7	42.4	070.7	25	4.2
Oct 16 63	15 36 32.5	44.2	114.8	33	4.2
Oct 17 63	01 22 08.1	44.5	114.7	33	4.7
Oct 20 63	13 29 26.6	31.1	115.6	14	4.9
Oct 24 63	09 52 37.4	44.4	114.8	33	3.8
Oct 25 63	15 05 22.3	35.4	116.9	14	4.5
Oct 26 63	20 20 14.6	43.1	111.2	35	4.3
Oct 27 63	14 50 19.7	33.1	115.6	14	4.3
Oct 27 63	14 56 55.0	33.0	115.7	14	4.4
Oct 27 63	15 24 10.6	33.0	115.6	14	4.2
Oct 27 63	15 30 43.4	33.0	115.7	14	3.4
Oct 27 63	15 58 50.2	44.2	114.8	33	3.6
Oct 27 63	18 07 44.4	33.0	115.6	14	4.5
Oct 27 63	18 12 49.2	33.2	115.7	14	4.1
Oct 27 63	18 22 05.3	33.0	115.7	14	4.5
Oct 27 63	18 49 36.3	33.0	115.6	14	4.6
Oct 27 63	19 38 15.2	33.1	115.7	14	*
Oct 28 63	00 30 39.3	33.0	115.6	14	3.8
Oct 28 63	08 14 15.6	33.0	115.6	14	4.4
Oct 28 63	15 55 36.0	33.1	115.7	14	4.0
Oct 29 63	05 39 33.0	43.1	111.6	33	4.0
Oct 29 63	07 01 42.7	40.4	124.7	38	4.7

Table 1 (Con't)

Oct	29	63	07	42	10.9	43.2	111.1	33	3.3
Oct	29	63	14	04	22.1	44.5	127.7	33	3.8
Oct	31	63	08	08	52.0	43.0	111.3	33	3.0
Nov	02	63	08	47	43.4	32.4	113.7	14	4.7
Nov	03	63	18	26	03.2	43.0	111.7	33	4.2
Nov	05	63	03	44	42.2	43.3	111.2	33	3.9
Nov	05	63	22	45	03.4	27.8	092.4	33	4.8
Nov	11	63	05	45	50.2	43.9	128.8	33	4.1
Nov	12	63	04	57	12.1	44.8	110.6	33	3.5
Nov	13	63	06	17	33.3	38.3	112.7	33	3.8
Nov	16	63	11	58	41.5	38.1	117.0	15	4.0
Nov	16	63	12	24	41.1	38.3	117.1	15	3.9
Nov	16	63	12	56	36.4	38.2	117.1	15	3.8
Nov	16	63	14	23	43.2	38.1	117.0	15	3.7
Nov	16	63	16	48	10.2	38.0	117.1	15	4.0
Nov	16	63	17	40	02.7	38.1	117.1	15	3.8
Nov	16	63	19	17	55.7	38.0	117.1	15	3.7
Nov	16	63	22	51	25.8	38.0	117.0	15	4.1
Nov	17	63	02	32	49.0	38.0	117.1	15	3.6
Nov	18	63	09	31	35.3	36.2	120.4	14	4.6
Nov	18	63	19	33	35.9	30.0	113.7	14	4.4
Nov	18	63	22	01	10.4	31.9	113.3	14	4.9
Nov	19	63	01	11	43.2	31.0	113.7	14	4.9
Nov	19	63	08	23	11.6	30.9	113.8	14	5.0
Nov	19	63	10	51	13.8	30.5	114.1	14	4.3
Nov	23	63	07	50	46.3	30.1	114.0	14	5.1
Nov	23	63	10	20	10.2	30.0	113.9	14	4.1
Nov	23	63	10	53	18.4	30.4	113.5	14	4.3
Nov	28	63	03	14	02.4	44.3	114.8	33	3.5
Nov	29	63	08	48	56.7	39.1	118.2	33	3.7
Nov	29	63	20	49	30.1	36.3	122.2	14	4.5
Nov	29	63	20	49	34.3	36.8	121.5	14	4.5
Dec	04	63	21	32	34.9	43.6	071.6	33	3.7
Dec	05	63	06	51	02.5	37.2	087.0	33	*
Dec	06	63	08	34	23.7	37.5	118.5	15	4.3
Dec	06	63	13	54	21.5	36.4	118.2	15	4.1
Dec	09	63	01	45	19.4	43.6	110.2	45	4.0
Dec	09	63	05	39	25.5	44.9	110.3	33	3.7
Dec	14	63	12	55	08.6	43.6	110.3	33	4.1
Dec	14	63	18	46	38.1	44.5	114.8	33	3.9
Dec	16	63	11	36	24.3	39.1	114.3	33	3.5
Dec	18	63	10	06	51.0	43.7	126.9	33	4.2
Dec	20	63	13	00	50.7	44.[illegible]	111.7	33	4.3
Dec	21	63	03	02	22.7	3[illegible].3	114.3	33	3.3
Dec	22	63	02	50	29.8	44.4	114.6	33	4.4
Dec	22	63	02	54	08.3	48.6	119.9	33	4.4
Dec	22	63	05	44	37.9	44.2	114.5	33	4.1
Dec	22	63	16	43	13.0	39.2	114.3	33	3.3
Dec	23	63	00	15	01.4	44.4	114.8	33	5.1
Dec	23	63	00	28	59.1	44.2	114.4	33	3.8

Table 1 (Con't)

Dec 24 63	01 50 59.5	44.8	111.5	33	3.5
Dec 24 63	14 51 11.9	39.6	110.4	33	4.1
Dec 24 63	17 54 19.8	44.8	111.2	33	4.7
Dec 25 63	20 04 10.7	44.2	114.6	33	3.7
Dec 25 63	23 55 15.2	39.1	114.2	33	3.6
Dec 26 63	03 58 51.6	39.2	114.2	33	3.5
Dec 26 63	14 40 06.6	39.8	110.3	33	3.7
Dec 27 63	02 36 22.3	45.7	123.3	37	4.5
Dec 28 63	08 22 19.3	44.8	110.9	33	4.3
Dec 28 63	14 26 19.6	39.2	114.2	33	3.5
Dec 28 63	15 19 58.0	39.0	114.0	33	*
Dec 28 63	15 50 14.2	39.1	114.1	33	3.3
Dec 29 63	01 42 13.7	39.1	114.2	33	3.4
Dec 29 63	04 02 04.0	39.1	114.2	33	3.4
Dec 29 63	04 06 12.2	[illegible].1	114.2	33	3.4
Dec 29 63	04 15 03.8	39.1	114.3	33	4.0
Dec 29 63	06 38 58.2	39.1	114.2	33	3.7
Dec 30 63	03 28 53.1	44.4	110.3	33	4.0
Dec 30 63	13 47 08.1	38.8	122.8	33	4.7
Jan 02 64	19 48 37.[illegible]	35.0	11[illegible].4	14	4.4
Jan 05 64	13 57 21.0	41.0	109.5	15	3.9
Jan 06 64	19 35 08.5	44.3	114.6	15	4.7
Jan 06 64	23 15 55.7	34.3	116.4	16	4.4
Jan 06 64	23 47 [illegible]1.4	34.3	116.5	14	4.4
Jan 07 64	11 55 34.6	39.1	114.2	3[illegible]	3.6
Jan 07 64	12 53 47.4	39.1	114.2	33	3.5
Jan 09 64	03 10 56.2	44.3	114.6	15	4.5
Jan 09 64	11 11 54.3	44.3	114.8	15	3.6
Jan 12 64	11 06 03.0	38.8	118.0	15	*
Jan 15 64	01 00 02.9	39.0	118.0	15	3.4
Jan 15 64	23 06 36.2	45.9	120.0	33	4.2
Jan 16 64	05 09 57.8	36.8	089.5	18	4.5
Jan 17 64	00 15 06.5	38.2	112.7	33	3.5
Jan 17 64	00 15 37.6	38.2	112.7	33	3.6
Jan 17 64	06 02 19.8	40.3	124.6	33	4.3
Jan 17 64	20 15 17.2	39.1	114.2	33	3.6
Jan 21 64	23 31 42.4	39.2	114.2	33	3.9
Jan 22 64	21 10 58.8	44.3	114.8	33	3.9
Jan 23 64	03 04 49.7	44.4	114.5	33	4.1
Jan 28 64	12 57 07.9	43.2	111.4	41	4.2
Jan 30 64	22 23 10.4	43.3	111.4	33	3.4
Feb 01 64	01 29 52.0	32.3	115.6	14	*
Feb 01 64	19 51 43.1	33.0	115.9	14	4.0
Feb 02 64	06 58 14.9	39.0	114.2	15	3.6
Feb 02 64	08 22 44.1	35.1	099.7	33	3.8

Table 1 (Con't)

Feb 02 64	12 15 11.0	43.3	111.4	30	3.1
Feb 03 64	05 55 44.3	43.2	111.1	30	4.1
Feb 03 64	10 21 20.8	39.8	120.0	15	3.4
Feb 05 64	19 45 58.0	35.1	118.8	14	4.5
Feb 05 64	20 18 10.5	35.4	118.6	14	3.7
Feb 06 64	07 53 48.8	37.5	113.2	15	3.7
Feb 06 64	08 02 28.3	42.0	112.3	30	3.8
Feb 06 64	11 13 34.8	42.1	112.4	30	3.7
Feb 06 64	16 17 52.0	37.2	116.3	30	*
Feb 07 64	13 20 08.1	42.1	112.4	25	3.7
Feb 07 64	22 07 49.9	35.3	118.8	14	4.3
Feb 07 64	22 10 52.8	35.4	118.8	14	3.9
Feb 08 64	03 37 22.8	32.9	115.7	14	4.3
Feb 08 64	05 29 21.6	34.3	118.6	14	4.1
Feb 08 64	06 22 09.1	44.4	114.5	30	4.3
Feb 13 64	19 46 38.8	40.5	077.9	15	*
Feb 18 64	09 31 10.5	34.8	085.5	15	4.4
Feb 20 64	03 29 36.1	44.4	114.7	30	3.7
Feb 20 64	20 19 48.9	39.4	114.2	14	3.7
Feb 24 64	10 53 51.7	35.8	116.6	14	3.2
Feb 26 64	20 32 54.4	40.3	124.6	33	4.6
Feb 28 64	01 09 43.1	43.6	110.2	30	3.4
Mar 02 64	07 29 23.4	39.6	111.9	33	3.9
Mar 05 64	12 40 52.9	39.2	114.2	33	3.4
Mar 09 64	02 06 30.8	37.6	118.4	16	3.9
Mar 09 64	20 49 55.8	35.3	118.7	16	4.3
Mar 13 64	01 20 18.1	33.2	083.4	40	4.4
Mar 14 64	17 42 25.3	37.7	118.7	16	3.6
Mar 22 64	15 56 19.8	38.8	118.8	16	3.8
Mar 22 64	16 30 55.2	38.8	118.7	16	4.5
Mar 22 64	16 39 50.3	38.8	118.8	16	4.0
Mar 22 64	18 14 49.6	38.8	118.8	16	3.4
Mar 22 64	18 17 43.0	38.9	118.8	16	4.0
Mar 23 64	15 32 55.0	38.7	118.8	16	3.9
Mar 24 64	23 57 07.8	38.7	118.7	16	3.5
Mar 25 64	08 46 16.0	40.4	124.4	33	4.5
Mar 28 64	03 33 44.5	35.9	114.9	05	3.7
Mar 28 64	10 08 45.0	42.9	101.6	41	5.1
Apr 07 64	15 31 32.5	45.0	111.6	33	3.2
Apr 07 64	19 09 04.7	38.6	118.7	15	4.1
Apr 09 64	18 43 16.2	39.4	119.1	15	3.7
Apr 10 64	21 29 56.9	39.2	114.2	15	3.6
Apr 11 64	03 25 04.8	38.5	118.7	15	3.6
Apr 12 64	13 11 01.6	39.0	118.8	15	3.9
Apr 12 64	15 37 49.6	43.2	111.4	15	4.0
Apr 13 64	11 36 30.4	43.3	110.8	15	3.7

Table 1 (Con't)

Apr 15 64	13 37 02.7	43.1	111.5	33	3.6
Apr 16 64	04 56 47.2	31.8	113.7	19	4.7
Apr 16 64	06 45 43.9	32.5	113.2	33	4.1
Apr 16 64	07 03 34.2	31.3	113.7	33	4.6
Apr 16 64	09 18 12.8	31.1	113.8	29	4.3
Apr 17 64	06 53 43.6	44.1	114.3	33	3.6
Apr 21 64	12 11 32.9	44.2	114.3	33	3.6
Apr 24 64	01 20 55.0	31.5	093.8	33	3.7
Apr 24 64	07 33 53.0	31.6	093.8	33	3.7
Apr 28 64	00 30 45.6	31.5	093.8	33	3.4
Apr 28 64	21 18 34.6	31.2	093.9	33	4.4
May 02 64	03 24 24.1	43.6	110.4	33	4.0
May 03 64	22 31 45.2	44.9	111.9	33	4.1
May 04 64	05 40 35.2	39.4	110.8	33	3.7
May 06 64	16 54 02.0	35.1	118.8	14	4.6
May 07 64	11 42 30.4	43.3	110.4	33	3.6
May 08 64	01 35 08.2	43.3	111.3	33	3.5
May 09 64	07 22 18.7	34.1	116.7	33	4.3
May 09 64	14 13 39.0	45.0	111.1	33	3.8
May 12 64	06 45 14.1	40.2	076.5	33	4.5
May 13 64	12 18 34.8	36.4	121.2	14	4.4
May 14 64	14 40 00.1	37.1	116.0	00	4.1
May 15 64	19 40 34.7	31.5	113.7	33	4.7
May 15 64	21 20 42.4	31.2	113.2	33	4.4
May 19 64	06 23 38.7	45.0	112.7	33	3.8
May 19 64	21 46 56.5	44.9	112.7	33	4.3
May 19 64	22 32 31.1	45.2	112.3	33	3.9
May 20 64	02 21 26.4	45.0	112.8	33	4.0
May 22 64	02 38 23.5	33.2	116.7	33	4.9
May 22 64	12 11 49.3	41.9	112.1	33	3.6
May 23 64	11 25 34.2	36.5	090.0	18	4.5
May 23 64	15 00 35.2	36.5	089.9	18	4.3
May 23 64	21 44 59.1	39.4	106.2	00	4.4
May 26 64	00 25 40.6	39.5	109.4	33	3.5
May 29 64	01 11 10.4	37.3	114.8	33	3.6
Jun 05 64	04 52 04.3	43.2	111.3	33	3.7
Jun 03 64	02 27 24.2	31.3	94.0	30	4.2
Jun 06 64	06 44 31.8	39.5	110.3	00	4.5
Jun 06 64	11 47 39.3	34.5	121.5	33	5.0
Jun 06 64	12 46 59.9	39.4	110.2	30	4.2
Jun 11 64	16 45 00.2	37.2	116.1	00	4.0
Jun 12 64	03 33 35.9	44.1	114.7	15	3.9
Jun 15 64	12 01 32.8	37.4	114.7	30	3.9
Jun 21 64	15 32 53.5	32.7	116.9	15	5.1
Jun 25 64	13 30 00.1	37.1	116.1	00	3.8
Jun 26 64	12 24 28.5	48.2	115.1	33	4.7
Jun 27 64	23 10 41.9	41.0	113.4	33	3.6
Jun 30 64	13 33 00.1	37.2	116.1	00	4.3

Table 1 (Con't)

Jul 08 64	05 55 42.2	38.4	118.4	10	4.4
Jul 11 64	02 47 31.2	42.4	110.8	33	3.3
Jul 12 64	11 58 57.0	40.2	124.7	33	4.2
Aug 02 64	13 29 07.3	39.1	118.1	15	4.0
Aug 04 64	07 22 51.6	39.3	118.1	15	3.6
Aug 04 64	11 13 25.2	39.7	106.0	33	4.0
Aug 12 64	05 04 50.9	39.4	112.0	15	3.9
Aug 13 64	21 51 01.7	46.5	112.2	15	4.1
Aug 17 64	22 33 43.2	33.1	115.8	14	4.5
Aug 18 64	08 47 18.2	45.1	110.5	33	4.2
Aug 21 64	22 03 51.6	37.0	115.1	33	3.8
Aug 22 64	03 28 11.8	42.9	104.7	51	4.5
Aug 22 64	07 34 17.2	32.0	113.8	15	4.6
Aug 24 64	01 51 03.3	38.8	112.3	33	3.4
Aug 24 64	01 55 38.3	39.1	112.2	33	3.4
Aug 24 64	10 18 58.5	45.0	111.4	33	4.3
Aug 26 64	16 58 51.6	43.8	102.2	15	4.4
Aug 28 64	06 50 46.6	37.0	113.1	33	3.5
Aug 30 64	22 57 35.3	34.1	118.4	14	4.4
Aug 31 64	17 03 36.4	35.5	118.4	05	4.5
Sep 01 64	19 49 13.8	36.7	122.0	14	4.1
Sep 04 64	20 20 24.8	37.4	118.6	14	4.1
Sep 06 64	18 51 18.6	34.2	114.0	15	3.3
Sep 06 64	19 03 35.3	39.2	111.5	15	3.7
Sep 08 64	00 27 55.5	44.3	114.8	33	3.9
Sep 10 64	06 19 50.7	41.9	107.8	33	4.1
Sep 12 64	08 45 05.5	44.2	114.6	33	3.7
Sep 16 64	05 34 30.7	37.1	114.9	33	3.4
Sep 16 64	12 22 44.3	34.4	119.4	14	3.8
Sep 16 64	14 40 38.4	31.4	114.0	33	4.3
Sep 17 64	22 07 40.2	38.7	071.9	00	4.6
Sep 17 64	22 17 20.0	42.8	110.8	33	4.0
Sep 18 64	22 01 28.3	44.9	111.2	41	3.6
Sep 20 64	07 42 27.7	41.3	124.9	33	4.3
Sep 22 64	06 52 10.0	44.4	114.8	15	4.3
Sep 22 64	08 03 51.0	44.3	114.7	33	3.8
Sep 23 64	18 09 38.3	35.9	114.8	15	4.4
Sep 24 64	12 51 32.0	38.3	118.4	15	3.1
Sep 30 64	17 51 34.8	35.3	118.0	33	4.2
Oct 01 64	12 31 24.6	45.7	122.8	33	5.3
Oct 02 64	10 39 33.2	44.8	111.4	33	3.8
Oct 05 64	01 24 55.3	32.9	115.8	33	4.5
Oct 09 64	00 33 46.2	38.9	110.9	33	3.4
Oct 09 64	02 26 02.4	47.8	114.2	33	4.6

Table 1 (Con't)

Oct 14 64	16 03 53.6	47.9	114.3	33	4.6
Oct 15 64	00 37 30.0	43.9	113.5	33	4.2
Oct 15 64	14 32 37.5	47.7	122.1	33	4.1
Oct 18 64	18 33 19.9	41.9	111.8	10	4.3
Oct 21 64	07 38 3[illegible].0	44.8	111.6	33	5.8
Oct 21 64	20 02 20.5	44.8	111.6	33	3.9
Oct 23 64	13 57 10.6	38.5	118.4	26	5.0
Oct 26 64	17 08 46.9	31.7	113.6	33	4.2
Oct 27 64	00 32 21.9	40.1	121.7	14	4.4
Oct 30 64	17 50 47.4	37.7	118.2	20	4.1
Oct 30 64	18 18 06.7	37.6	118.5	20	3.8
Oct 30 64	19 01 45.7	37.8	118.2	20	*
Oct 30 64	19 03 12.3	37.7	118.0	20	4.4
Oct 30 64	19 40 30.2	38.0	117.7	20	*
Oct 30 64	23 02 59.5	37.7	118.1	20	4.1
Oct 31 64	11 57 31.7	38.2	117.8	20	3.7
Oct 31 64	19 35 24.7	38.0	117.8	20	4.0
Nov 01 64	20 41 07.0	38.0	117.8	33	3.8
Nov 02 64	11 38 55.7	37.6	118.0	32	4.4
Nov 03 64	18 58 41.1	37.7	118.1	10	4.1
Nov 04 64	08 42 53.8	39.6	110.3	00	4.0
Nov 04 64	11 50 32.1	37.6	118.2	33	3.6
Nov 04 64	11 53 56.2	37.5	118.4	33	3.7
Nov 08 64	01 19 17.2	35.8	120.2	14	4.4
Nov 12 64	20 07 25.4	37.7	118.0	20	3.8
Nov 13 64	05 05 10.8	37.6	118.0	20	4.2
Nov 13 64	23 09 53.8	44.8	111.0	10	4.1
Nov 16 64	02 46 43.4	36.9	121.8	33	5.2
Nov 17 64	10 11 00.1	44.6	110.9	33	3.9
Nov 17 64	14 52 26.5	33.8	116.5	14	4.5
Nov 18 64	10 26 50.0	44.1	114.1	33	3.6
Nov 21 64	17 25 57.5	32.8	116.0	14	4.7
Nov 23 64	23 52 11.2	37.6	118.0	10	4.4
Nov 23 64	23 52 29.7	37.6	118.0	14	4.2
Nov 24 64	03 01 07.7	45.3	111.7	10	3.9
Nov 25 64	02 50 05.0	37.4	081.5	00	4.5
Nov 29 64	14 25 23.9	32.9	115.6	14	4.5
Nov 30 64	21 16 16.6	36.9	121.7	14	3.8
Dec 01 64	15 28 20.9	37.8	117.8	33	3.7
Dec 02 64	09 17 50.8	37.5	117.9	33	3.9
Dec 04 64	11 39 58.0	35.6	118.4	14	3.3
Dec 11 64	19 21 51.9	39.1	118.3	33	4.2
Dec 12 64	07 59 24.6	39.6	117.9	33	3.4
Dec 12 64	12 49 04.9	39.7	119.7	33	*
Dec 12 64	13 14 01.5	39.1	114.2	33	2.7
Dec 12 64	13 32 01.7	39.[illegible]	119.6	33	3.8
Dec 14 64	08 15 41.4	38.0	117.8	33	3.6
Dec 20 64	21 56 03.2	35.9	114.9	05	3.7
Dec 20 64	22 18 21.7	[illegible]	114.8	05	3.0
Dec 21 64	21 38 47.3	45.2	112.7	33	3.5

Table 1 (Con't)

Dec 21 64	21 54 58.0	44.9	112.7	44	3.9
Dec 21 64	22 55 08.8	45.0	112.0	33	3.5
Dec 22 64	10 28 46.7	44.9	112.5	33	4.3
Dec 22 64	15 45 28.3	45.4	112.2	33	4.0
Dec 24 64	22 51 34.7	44.7	110.8	33	4.0
Dec 25 64	14 09 48.1	32.3	113.7	33	4.4
Dec 26 64	20 58 14.4	39.6	110.3	00	3.9
Dec 31 64	10 41 03.6	35.0	116.6	14	3.9

*Magnitude not computed due to limited data.

PART II

NETWORK CAPABILITY

1. Introduction

Part II of this report comprises an evaluation of the capability of the network of United States seismograph stations to record earthquakes in the conterminous United States. The basic information required to accomplish this evaluation is: the geographic distribution of recording stations; the measured or assumed noise distribution at each site; the variation of signal amplitude with distance; the signal to noise ratio required for signal detection; and a representative sample of epicenters with specified magnitudes or ranges of magnitudes.

From this information the capability of individual stations to record the sample of events is computed using probability theory. With the minimum number of stations required for epicenter location specified, the network capability is established from the combined station probabilities at various levels of probability. The minimum number of stations is taken to be five in conformity with the requirements of the Coast and Geodetic Survey's hypocenter program. A further evaluation, related to the accuracy of epicenter determination, is accomplished by establishing a measure of the azimuthal distribution of the predicted recording stations about the epicenter. Finally, 344 earthquakes with epicenters in the conterminous United States,

which were reported on the Coast and Geodetic Survey P.D.E. cards during 1963, are used both to evaluate reporting procedures and the reliability of input parameters.

A statistical treatment of the network evaluation problem has bee eported by Latter, et al (1961). Their treatment differs from that of this report in two significant ways. Firs y assumed a uniform distribution of background noise for all recording sites; second they investigated the twork requirements for recording seismic events of a given location and energy yield. In this report the capability of an established network of seismograph stations is evaluated. The background noise is treated as a function of the recording site.

2. Station Distribution and Instrumentation

The geographic distribution of seismograph stations in the conterminous United States is shown in Figure 18. Each station is represented by a symbol indicating the network to which it belongs. For the purpose of this study the composite of all stations shown on Figure 18 is referred to as the United States network of seismograph stations.

The Coast and Geodetic Survey maintains, entirely or on a cooperative basis, only 18 widely separated seismograph stations in the conterminous United States. The remainder are maintained by several universities and other groups as indicated on Figure 18. Generally, these networks have grown out of interest

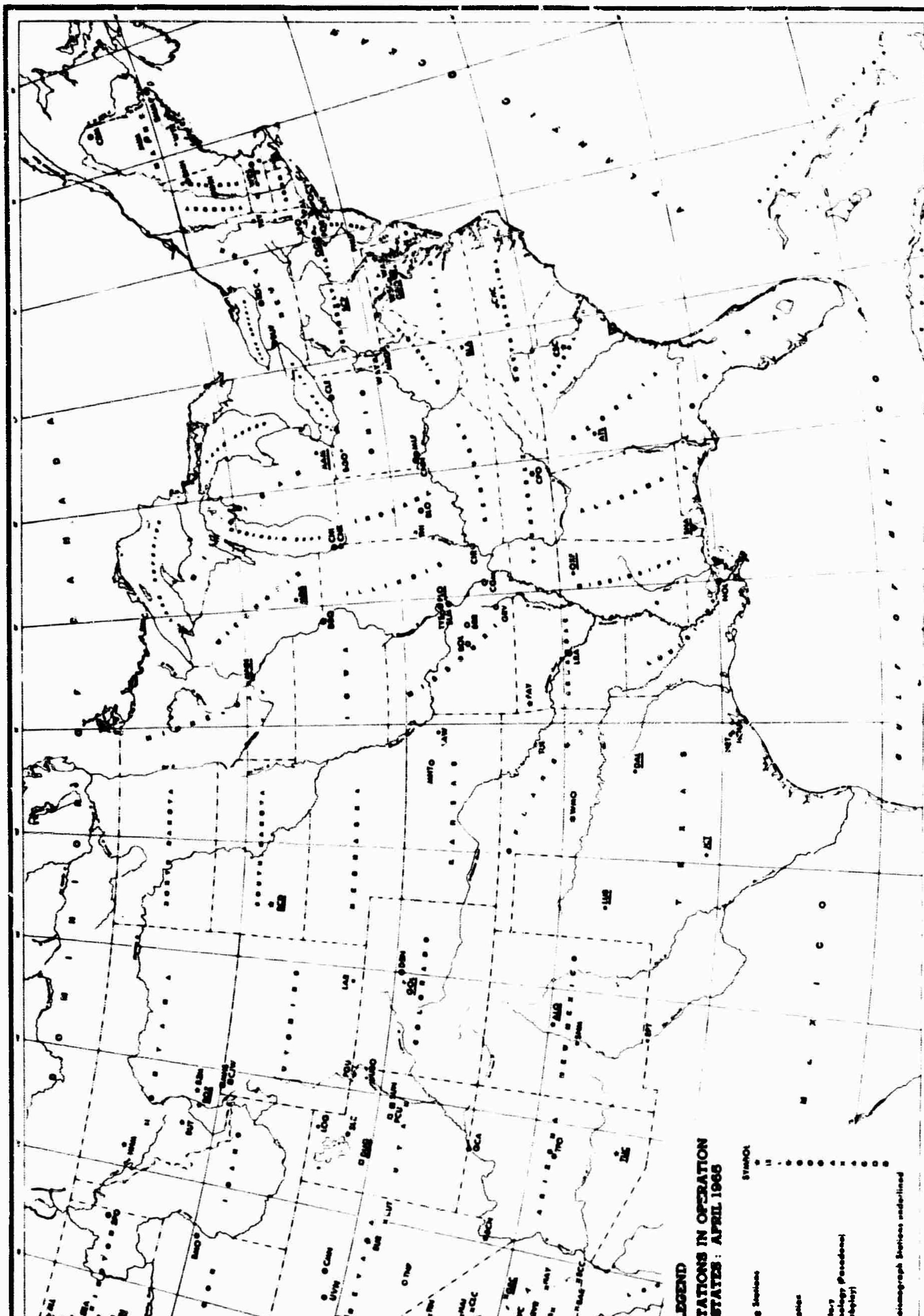


Figure 18. Seismograph Stations in Operation in the United States April, 1965.

in particular regions. As a result, rather dense station networks exist in the California area, the Yellowstone Park area, the southeast Missouri area, and the southern New York area, while other areas remain incompletely covered. With the exception of California, which has the most dense network of stations, no attempt has been made to provide systematic coverage of a region.

This condition has been somewhat corrected with the installation of the World Wide Network of Standard Seismograph Stations which was begun in 1961. At this date, 25 WWNSS stations are operational at widely separated sites in the conterminous United States providing greatly increased station coverage. The five widely spaced array observatories (see Figure 18) provide excellent additional control.

A majority of the stations in the United States are now equipped with short period seismometers which are capable of being operated at high gains. The 25 WWNSS stations are equipped with three component sets of short period Benioff and long period Sprengnether seismometers. All of these stations have accurate and uniform time control. Other stations are equipped with either the large short period or the portable short period Benioff seismometers. A variety of instruments are in use at

the remaining stations. There is less uniformity in the long period instrumentation among those stations which are not a part of the WWNSS, and many of them are not equipped with long period instruments. This, however, is of no consequence in the present study. The instruments in use at each station, except the array stations, are listed in Appendix I.

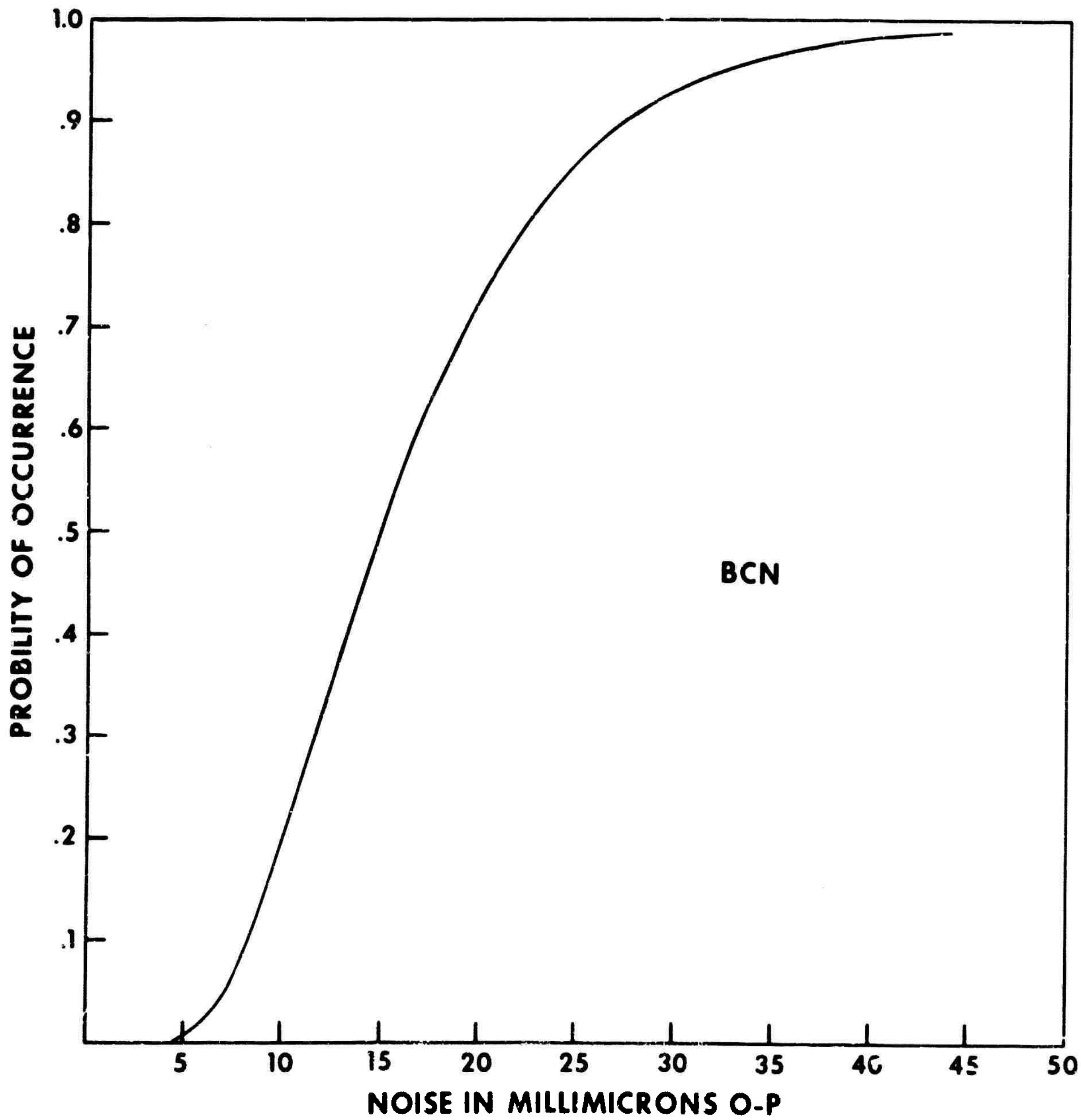


Figure 19. Probability of Noise Occurring at or Less than a Given Amplitude at Boulder City, Nevada.

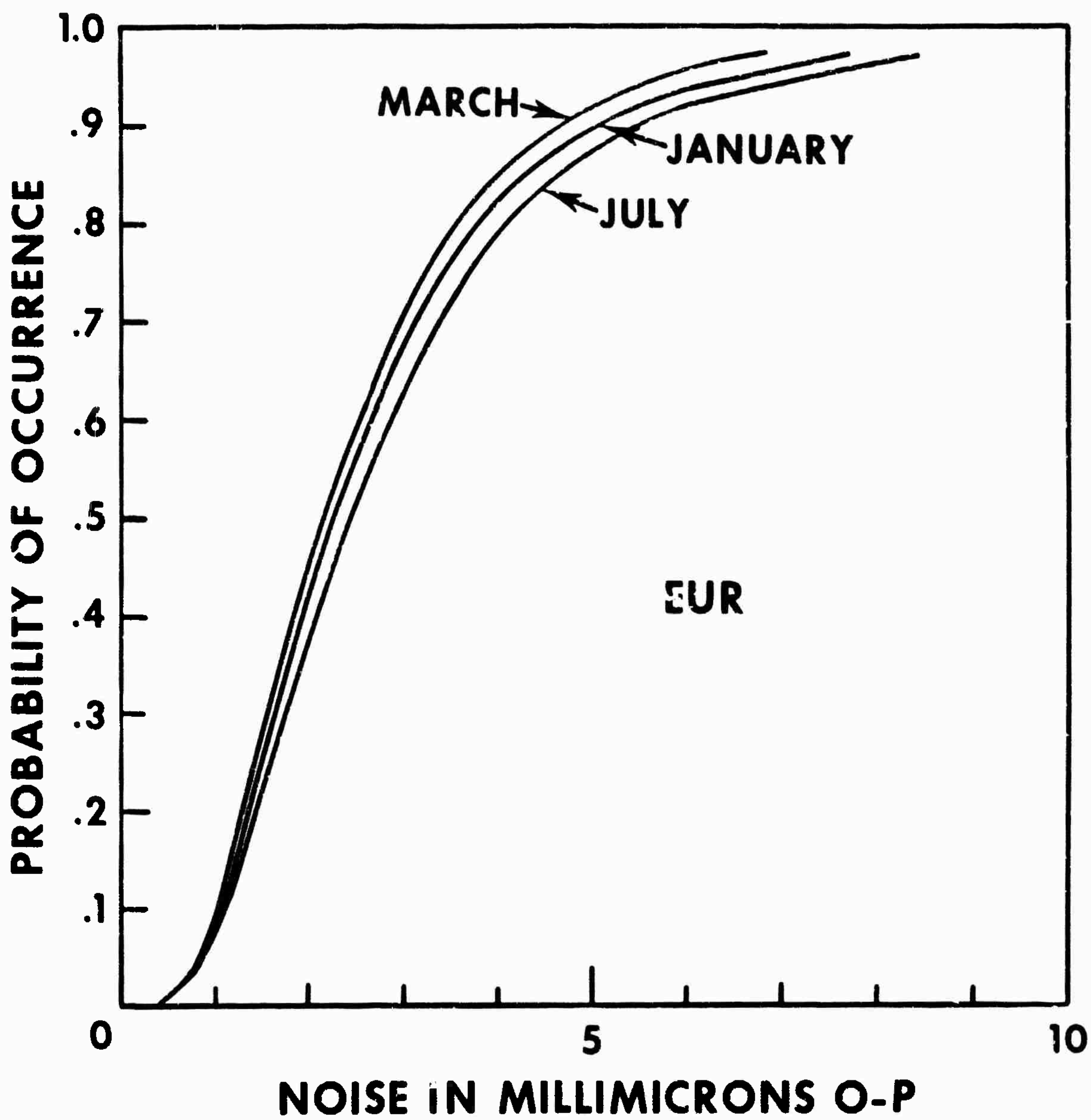


Figure 20. Probability of Noise Occurring at or Less than a Given Amplitude at Eureka, Nevada.

3. Station Noise Distribution

At most sites it is the background noise that limits the maximum sensitivity at which the instruments can be operated. Consequently, an evaluation of the network detection capability requires specification of the interfering noise process. Seismic noise, which may be defined as any ground motion that is

not caused by an earthquake or an explosion, has received considerable attention in recent literature. A review of the subject is given by Iyer (1964) with references to the literature.

Seismic noise may be characterized as a composite of ambient microseismic noise, transient and continuous local cultural noise, random local wind noise, and instrumental noise. Ambient microseismic noise can be correlated to some degree with physiographic province, gross and local geology, and distance from the ocean or other large bodies of water. Random local contributions, however, are the dominant noise sources at most locations in the frequency band of interest in this study. As a result, the background noise varies radically over

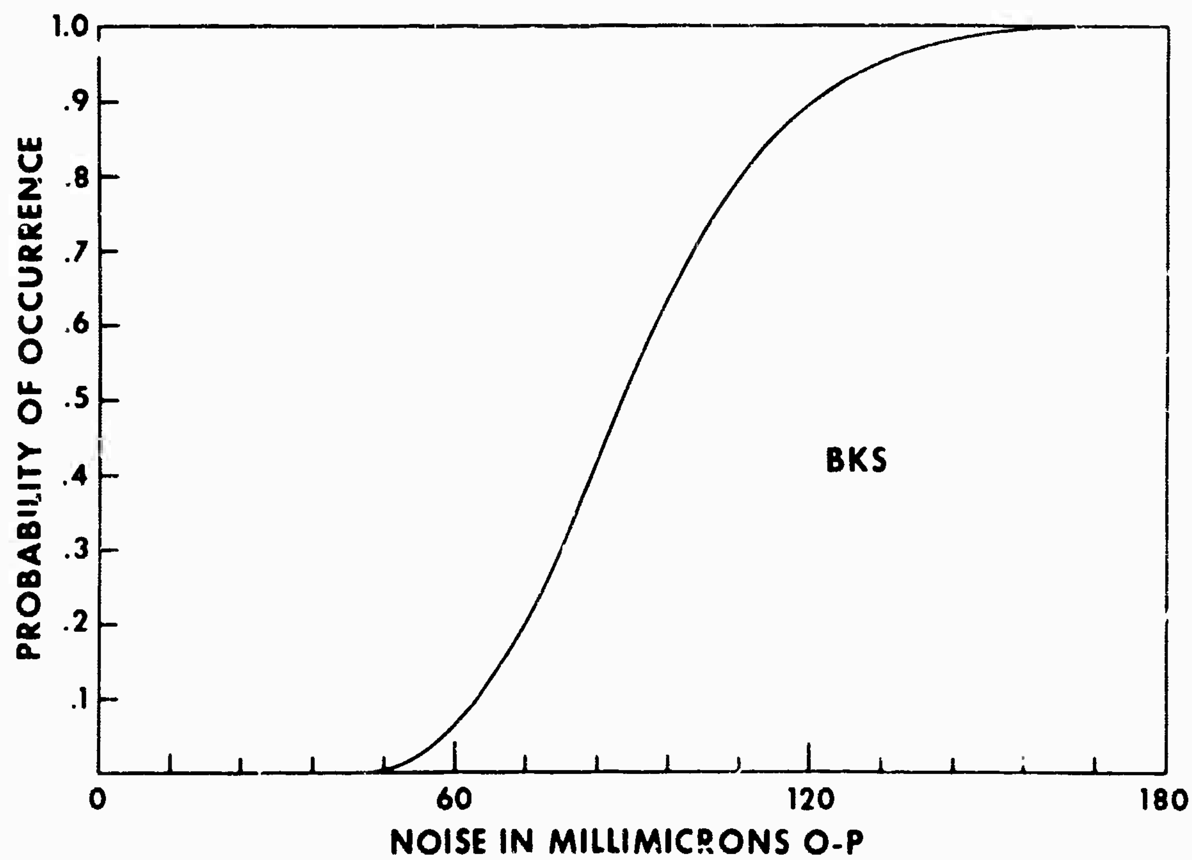


Figure 21. Probability of Noise Occurring at or Less than a Given Amplitude at Berkeley, California (WWNSS).

short distances. Accordingly, a reliable statistical study of background noise requires sampling at each site over a sustained period of time.

For the present study we are concerned with the long-term amplitude distribution of the background noise in the frequency band 0.6 cps to 2.0 cps. The method of sampling consists of measuring the maximum amplitude in this frequency band twice daily for periods representing the four seasons of the year. The resulting sample is used to compute the probability distribution of the background noise amplitude. Obtaining a sufficient background noise sample at all of the stations used in this study is a time consuming task. Hence, use has been made of published noise studies (Hair and Funk, 1964; Guyton and Alsup, 1963) which were performed in a manner similar to that described above.

The probability distribution of the background noise at 12 sites representing different physiographic and geologic provinces is shown in Figures 19 to 30. Figures 20, 24 and 25 show seasonal variations of the background noise at three stations.

Figure 31 is a display of the generalized average background noise at one cycle per second in the conterminous United States. It is taken from the work of Guyton and Alsup (1963)

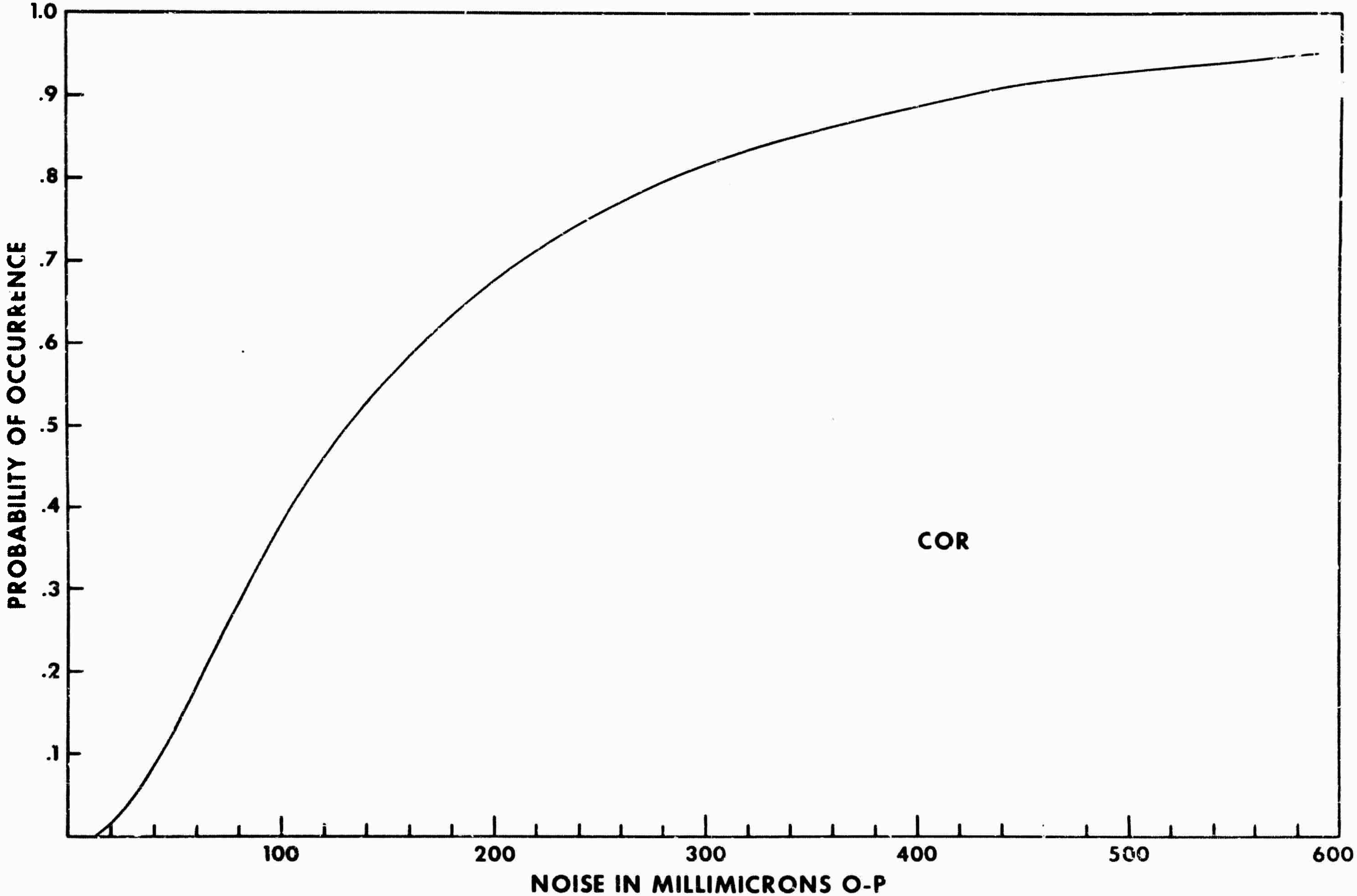


Figure 22. Probability of Noise Occurring at or Less than a Given Amplitude at Corvallis, Oregon.

with modifications according to the data of Hair and Funk (1964), and the data of this report.

The method of maximum satisfactory operational magnification described by Guyton and Alsup (1963) is used to establish the average background noise level at 70% of the stations. It is assumed that the maximum tolerable trace displacement due to background noise is 1.5 mm. Amplitudes greater than 1.5 mm will generally result in overlapping of the traces. The station

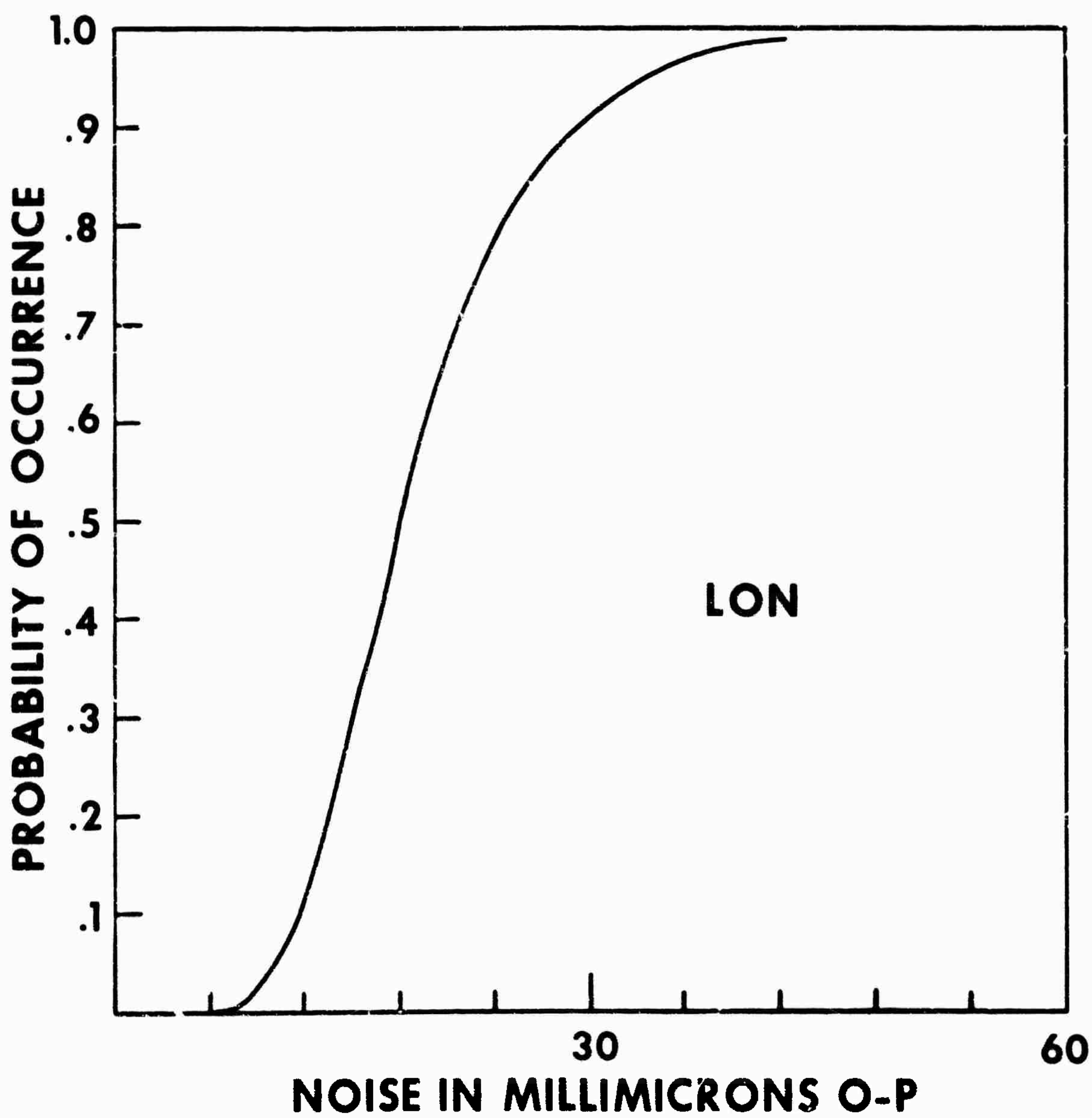


Figure 23. Probability of Noise Occurring at or Less than a Given Amplitude at Longmire, Washington.

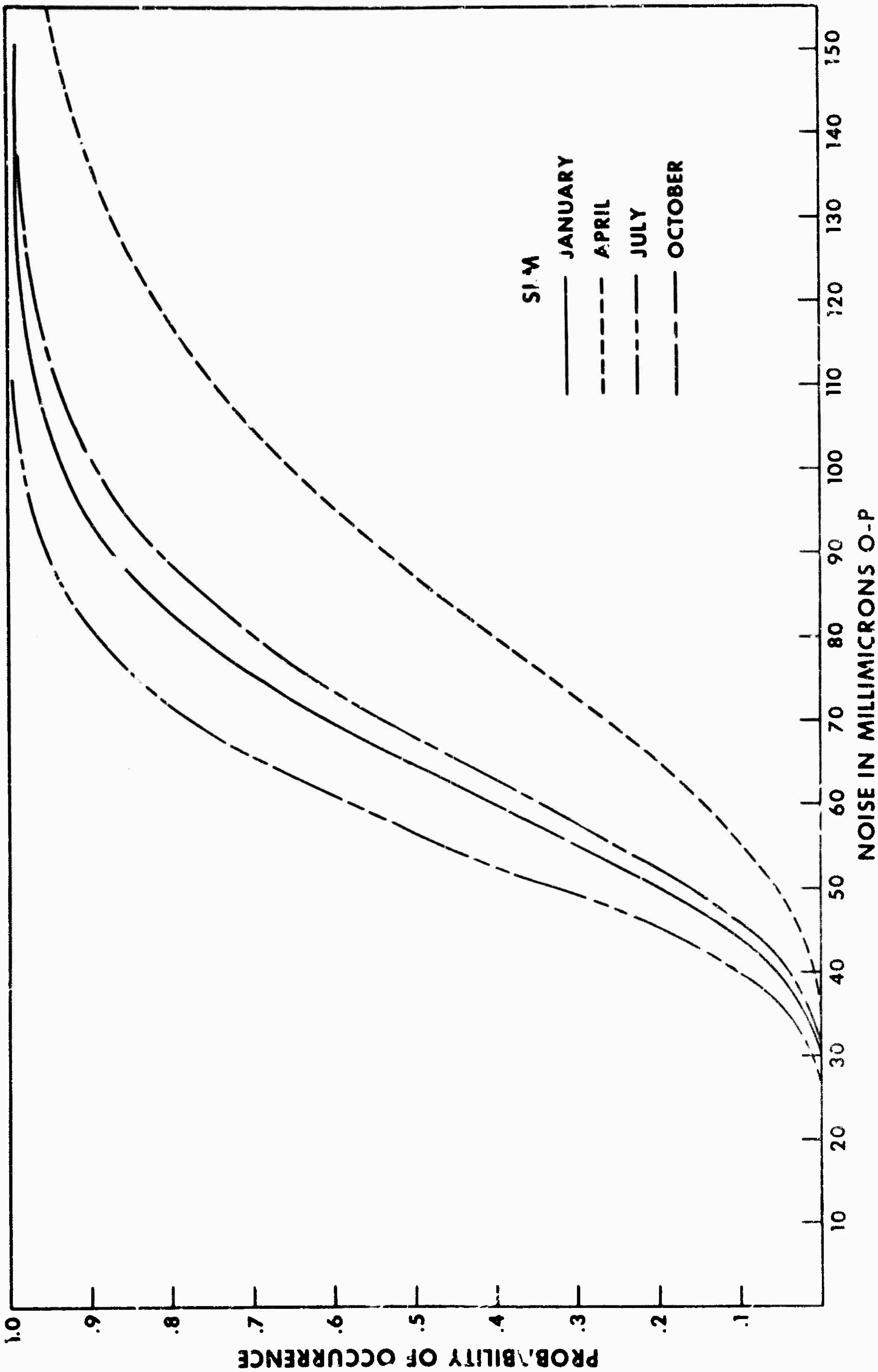


Figure 24. Probability of Noise Occurring at or Less than a Given Amplitude at St. Louis, Missouri.

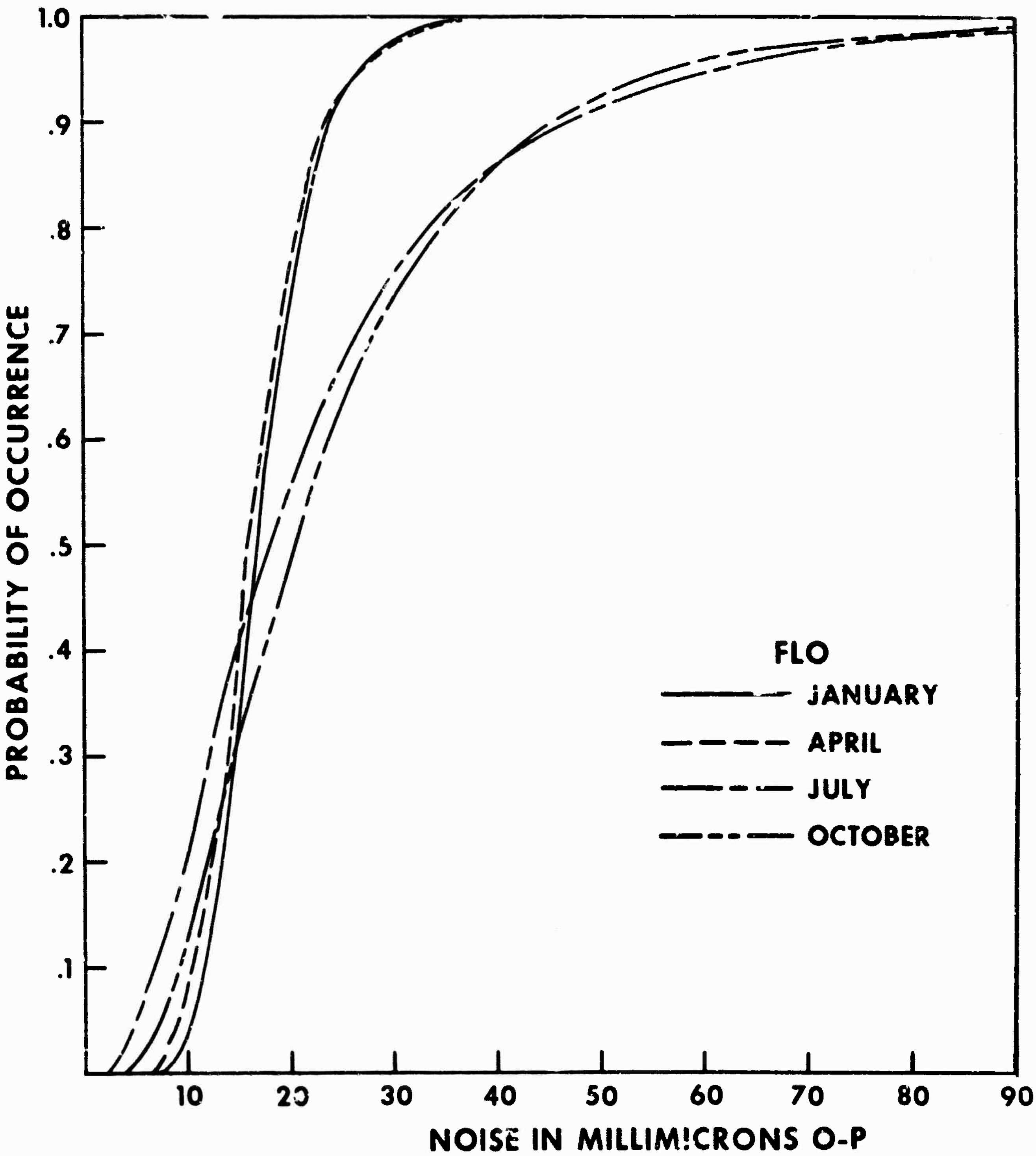


Figure 25. Probability of Noise Occurring at or Less than a Given Amplitude at Florissant, Missouri.

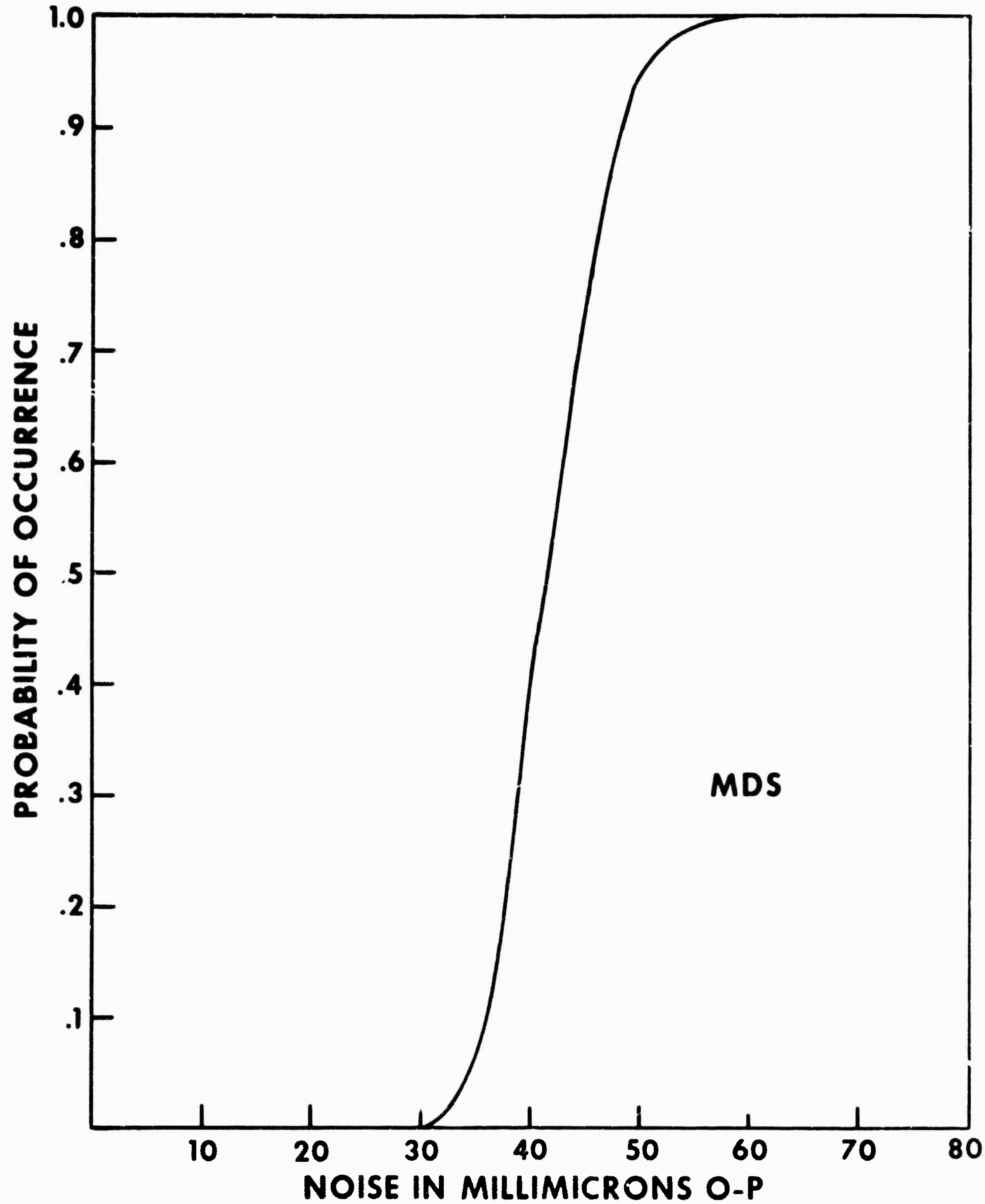


Figure 26. Probability of Noise Occurring at or Less than a Given Amplitude at Madison, Wisconsin.

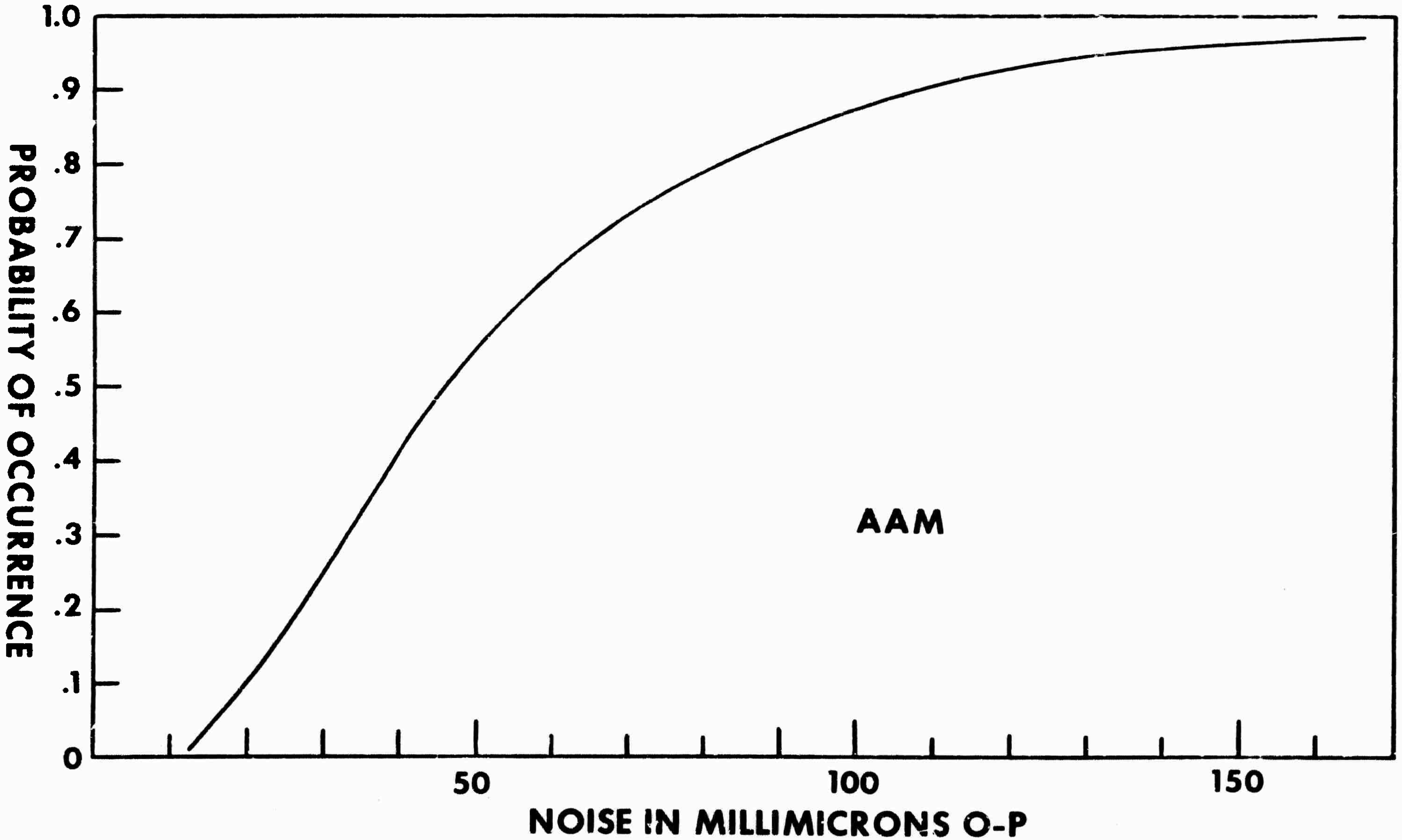


Figure 27. Probability of Noise Occurring at or Less than a Given Amplitude at Ann Arbor, Michigan.

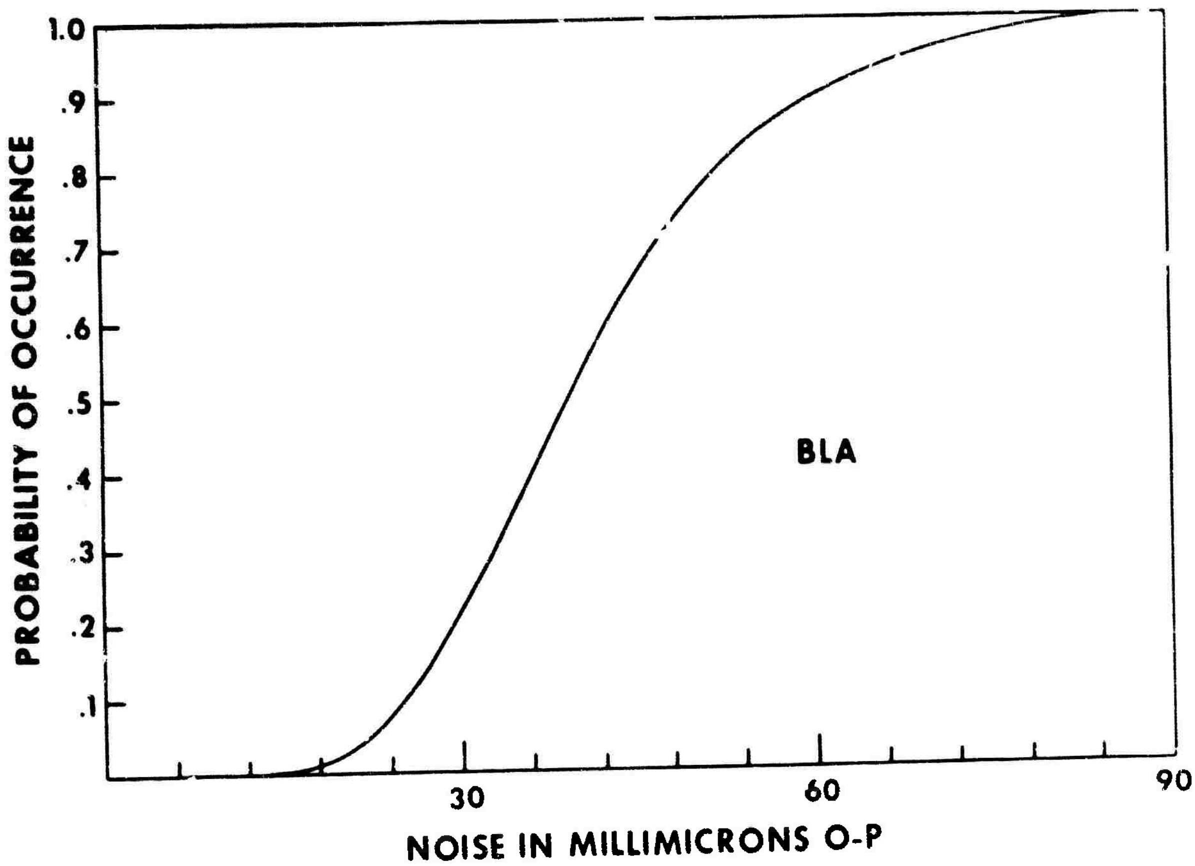


Figure 28. Probability of Noise Occurring at or Less than a Given Amplitude at Blacksburg, Virginia.

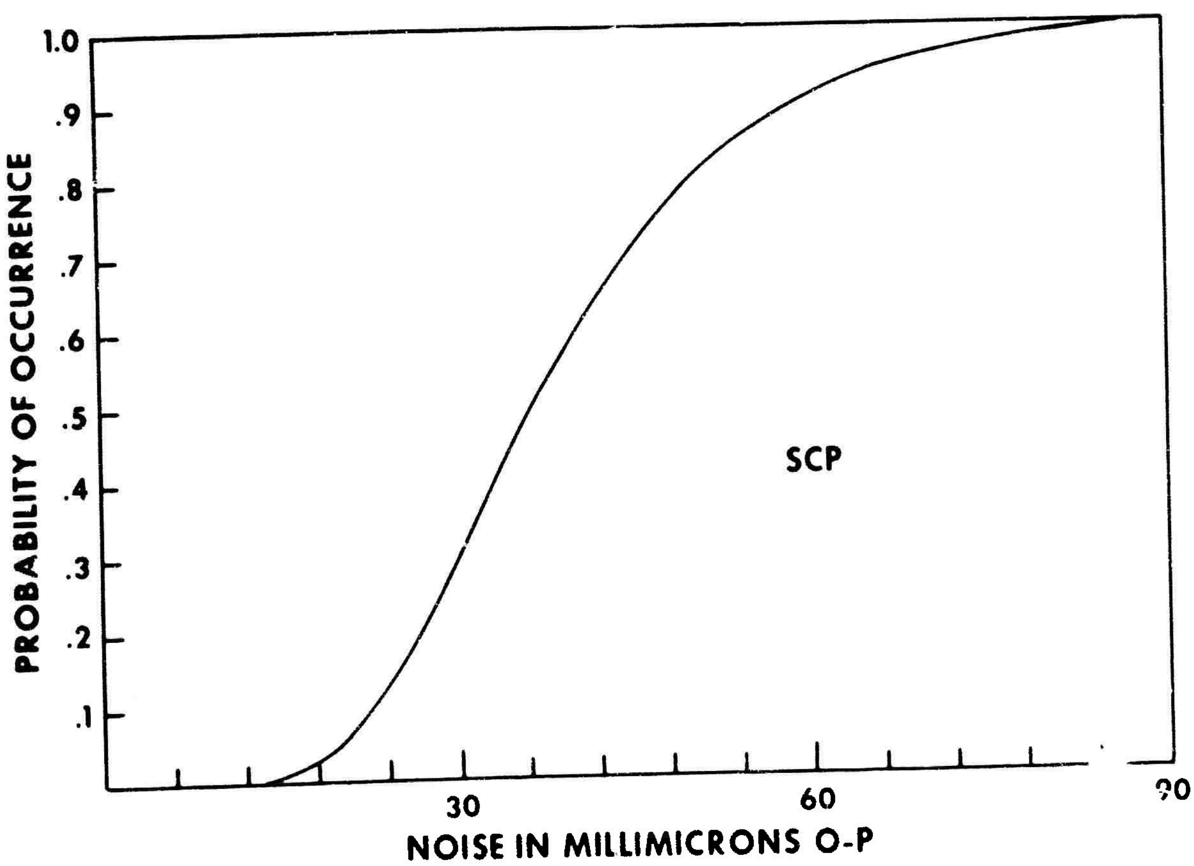


Figure 29. Probability of Noise Occurring at or Less than a Given Amplitude at State College, Pennsylvania.

magnification at 1 cps is then used to determine the ground motion which produces a trace amplitude of 1.5 mm. This value is taken to be the average background noise of the station in the frequency band of interest in this study. For statistical treatment of the data, it is assumed that the background noise at these sites has the same probability distribution as nearby sites at which measurements were made.

4. Signal to Noise Ratio and Regional Variation of Signal Amplitude

In order to determine network capability a criterian relating the minimum detectable signal to the background noise must be used. In visual analysis, seismic signals are recog-

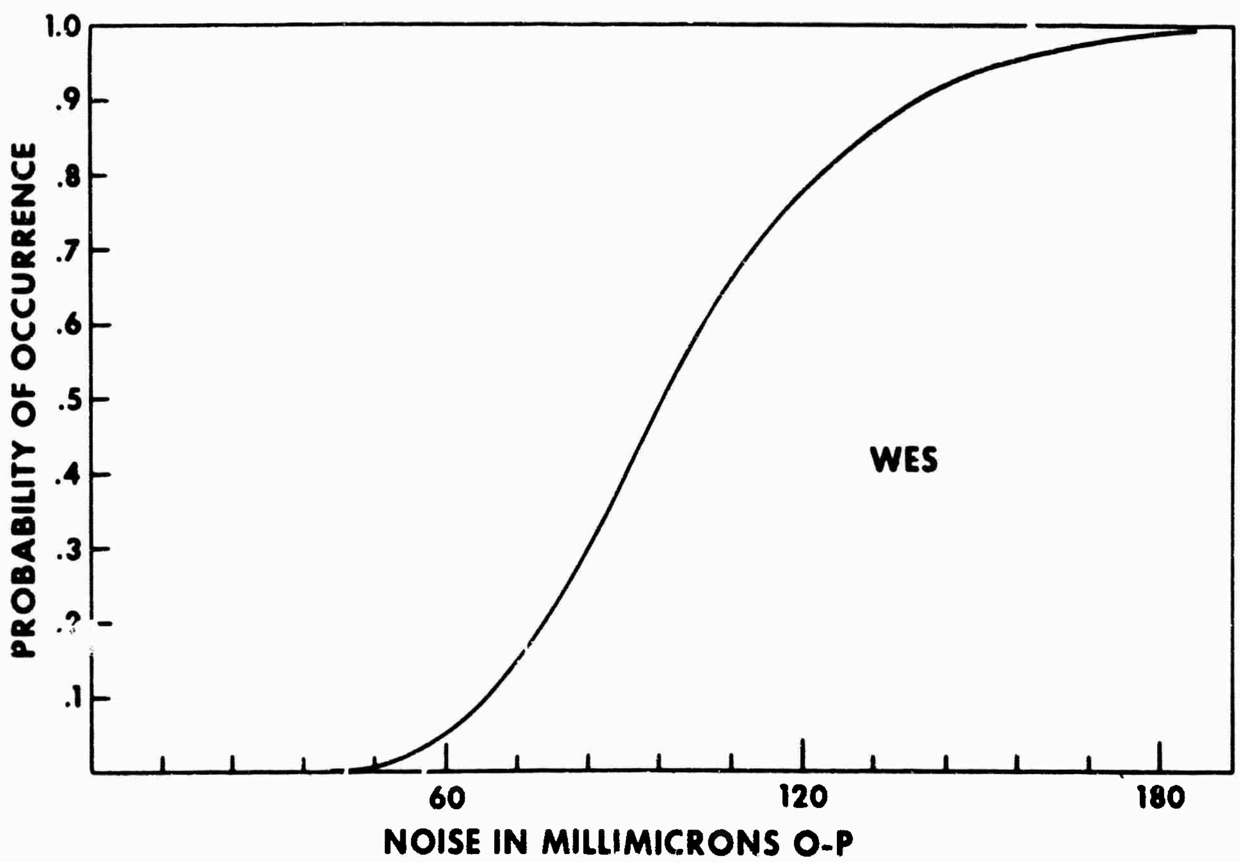


Figure 30. Probability of Noise Occurring at or Less than a Given Amplitude at Weston, Massachusetts.

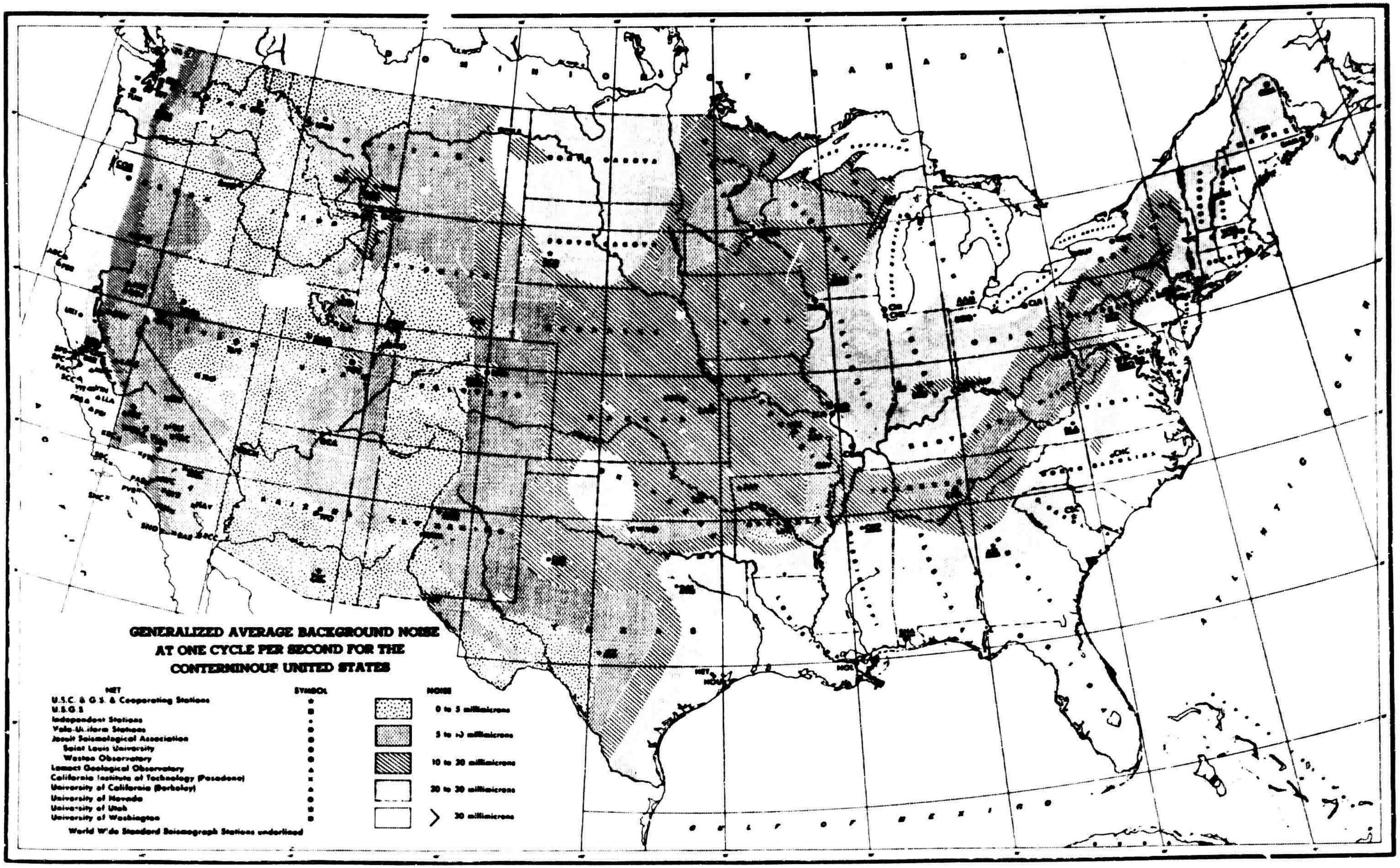


Figure 31. Generalized Average Background Noise at One Cycle per Second for the Conterminous United States. (After Geo. Tech. monthly report 33 AFTAC Project No. VT/1139)

nized in background noise by differences in frequency and/or amplitude. It is clear that signals can be visually detected in noise which is outside of the frequency band of interest, even when their amplitude is less than that of the noise. Of particular interest, then, is the minimum signal to noise ratio (s/n) for visual detection of a signal in background noise with frequency near that of the signal.

The recent research of McCoy (1964) has direct bearing on this topic. He investigated the detectability of a sinusoidal signal in the presence of band limited random noise with a gaussian amplitude distribution. The variable parameters were: the bandwidth of the noise, the signal to noise ratio, and the signal duration. It was noted that both the bandwidth of the noise and the duration of the signal influence the detectability of the signal for s/n constant. For both s/n and signal duration constant, visual detectability increases as the bandwidth of the noise is increased. For both s/n and noise bandwidth constant, visual detectability increases with increase in signal duration. For a uniform noise spectrum and a signal duration of three cycles or greater, a sinusoidal signal was found to be visually detectable independent of the actual noise bandwidth for s/n = 2. These findings remain to be tested for complex seismic wave forms in background noise with spectral and amplitude distribution of actual seismic

noise. However, McCoy (1965) suggests that s/n = 2 will allow visual detection of seismic signals in most actual cases. Accordingly, this value has been taken as the threshold s/n for this study.

A complete network evaluation must take into consideration the regional variation of signal amplitude. For the geologic and physiographic conditions which combine to reduce the background noise also reduce the signal amplitude in the same frequency band. Guyton (1963) in studying signal amplitudes from 130 earthquakes recorded by 27 standardized seismographs in the United States, found that the signal amplitude normalized for distance varied by a factor of five. Furthermore, he found that these variations in amplitude could be correlated with differences in regional and local geology. At the same sites, the background noise varied by a factor of 12, while s/n varied by a factor of six.

These findings support the suggestion of Carpenter (1964) that maximum s/n and not minimum noise may be the best measure of site efficiency. Accordingly, for the purpose of evaluating the network detection capability, s/n is considered to be the most accurate measure of station detection capability. With this in mind, s/n has been effectively made a variable which is a function of the recording site. This is accomplished by applying station corrections based on Guyton's results according

to the geologic province in which the station is located. Corrections of this type clearly do not account for the influence of local geological conditions on signal reception. However, they provide a more accurate assessment of the network detection capability than could be gained by considering variation of background noise alone.

5. Network Detection Capability

Although computer determinations of earthquake epicenters allow large quantities of input data to be rapidly processed, careful and complete reading of seismograms remains a time-consuming task. Therefore, for rapid reporting of epicenters, it is desirable to keep the number of reporting stations to the minimum required to accomplish the level of earthquake recording needed for seismicity studies. A complete evaluation of the network detection capability then requires an appraisal of the individual station capability and its contribution to the network detection capability as well as an evaluation of the detection capability of the network as a whole.

5.1 Computational Procedure

The method of evaluating network capability employed for this study has been described by Booker (1964). This statistical approach depends on considering the recording of seismic events by a large number of stations as independent events. The

primary input information is the number and location of stations, the mean and standard deviation of the noise amplitude, the attenuation of signal amplitude with distance, and a representative sample of epicenters with assigned magnitudes or ranges of magnitudes. The probability of detecting an event at a single station is equivalent to the probability of the noise amplitude occurring at or less than the quotient of the computed signal amplitude and the s/n. The combined event station probabilities provide the event network probability.

5.1.1 Amplitude versus Distance

Amplitude calculations are in terms of the body wave magnitude adopted by the Coast and Geodetic Survey. For each event the magnitude (m_b) is specified. The signal amplitude at one cps for each station, is computed from the relation

$$m_b = \log A + f(\Delta)$$

where $f(\Delta)$ represents the signal attenuation as a function of distance. For distances to 10 degrees the signal amplitude is attenuated according to the inverse cube of the distance. For distances of 16 degrees or greater $f(\Delta)$ is based on Gutenberg and Richter (1956) Q values for P-waves from shallow focus earthquakes. The inverse cube value at 10 degrees is scaled to join the Gutenberg-Richter values at 16 degrees, to provide an amplitude attenuation function over the entire range of distances.

An apparent discontinuity in the curve at 10 degrees results from the scaling procedure. This does not alter the final results, however, as the error due to the discontinuity is less than the smallest increment of magnitude considered in the analysis.

5.1.2 Detection Threshold

An array of events consisting of 258 epicenters distributed at two degree intervals over the conterminous United States is used to determine the detection capability of each station of the entire United States station network. At each epicenter the magnitude is allowed to range from 3.0 to 4.5 in increments of one-tenth units of magnitude. The distance, amplitude, and probability of detection are computed for each station of the network for each event of the array. A station is considered to record an event when the probability of detection is equal to or greater than 0.5. The 0.5 probability is called the "station threshold probability," and the event magnitude which produces it is called the "station threshold magnitude," for the corresponding epicentral distance. In many instances the station threshold magnitude is greater than 4.5 for a given epicenter location. When this occurs it is obtained by specifying the signal amplitude required to produce the

threshold probability. By a reverse computation the event magnitude required to produce this amplitude is computed. This procedure results in a continuous threshold magnitude as a function of distance for each station. The resulting curves are displayed in Appendix II.

The network is said to record an event when at least five stations (the number required for location by Coast and Geodetic Survey) reach the threshold probability. The magnitude which produces this condition is called the "network threshold magnitude," for the epicenter location. It is clear that the network detection probability may exceed 0.5 for this event.

5.2 Station Detection Capability

The individual station detection capability is evaluated by two methods. The first method is to compare the average station threshold magnitudes for the set of events representing the entire United States and for subsets of events representing areas of known high seismicity. Subsets of events have been selected to represent southern California, northern California, the eastern Basin and Range, and southeast Missouri. The results are summarized in Table 2. The second method is to plot the station threshold magnitude versus distance. The resulting curves are displayed in Appendix II.

The data of Table 2 provide a basis for grouping stations according to their expected contribution to the total network capability. Subsets of events provide information on station performance only in limited areas and, consequently, over a narrow range of distances. Accordingly, the average station threshold magnitude for the set of events which represents the entire United States is considered to provide the best basis of comparison.

Stations which have an average threshold magnitude of 4.20, or less, are grouped as high performance stations. These have threshold magnitudes at or below the lowest magnitude above which all earthquakes in the conterminous United States will be detected. They, accordingly, contribute substantial control governing the network capability over much of the United States, especially in areas of low station density. Seven of the 51 stations which regularly report for P.D.E. (shown by an asterisk in Table 2) satisfy this requirement. One additional station which does not presently report regularly for P.D.E. (Unionville, Nevada, UVN) also falls within this group. Thus, only eight stations of the total United States network may be expected to provide network control essentially anywhere in the conterminous United States. All have peak magnifications in excess of 400,000.

TABLE 2
AVERAGE STATION THRESHOLD MAGNITUDE

Station	All United States Earthquakes	Southern California Earthquakes	Northern California Earthquakes	Eastern Basin and Range Earthquakes	Southeast Missouri Earthquakes
AAM	4.85	5.22	5.25	4.77	5.03
ALQ*	4.00	4.25	4.09	3.96	3.92
ARC	5.78	5.83	4.65	5.99	5.99
ATL	4.82	5.16	5.25	4.88	4.73
BAR*	4.41	3.30	4.20	4.50	4.42
BCN*	4.67	3.89	4.60	4.56	4.54
BGO	5.27	5.64	5.67	5.20	5.33
BKS*	4.99	4.50	3.75	5.25	5.17
BLA*	4.85	5.24	5.27	4.99	5.07
BLL	5.06	4.85	5.30	5.09	5.27
BLO	4.71	4.95	5.02	4.54	4.04
BMO*	3.79	4.07	3.76	3.66	3.76
BOZ*	4.46	4.61	4.78	3.96	4.31
BRK*	5.40	4.89	4.11	5.65	5.58
BRR	4.79	4.81	4.92	4.57	3.58
BUT*	4.82	4.95	5.18	4.33	4.67
CBM	4.94	5.09	5.07	5.27	4.62
CGM	4.79	4.90	5.02	4.58	3.48
CHC*	5.09	5.47	5.47	5.28	5.38
CHI*	5.64	5.87	5.93	5.45	5.39
CJW	4.96	5.14	5.31	4.34	4.74
CLC*	4.45	3.35	3.90	4.58	4.47
CLE*	5.43	5.85	5.89	5.48	5.69
CNC	5.47	4.77	3.99	5.73	5.64
CNY	5.71	6.04	6.01	6.02	5.62
COR*	5.40	5.55	5.14	5.57	5.61
CPO*	3.90	4.19	4.27	3.83	3.41
CSC*	5.07	5.45	5.48	5.24	5.30
DAL	5.06	4.95	5.08	5.08	5.29

Table 2 Cont.

DBQ	5.05	5.17	5.21	4.87	4.89
DUG *	4.26	4.36	4.28	3.64	4.04
EMM	5.41	5.57	5.55	5.75	5.09
EPT	4.66	4.90	4.59	4.74	4.51
EUR *	4.06	3.82	3.54	3.80	3.93
FAY *	5.01	4.92	5.05	4.93	4.42
FGU *	4.73	5.02	5.03	3.99	4.51
FLO *	4.75	4.81	4.91	4.53	3.59
FOR	5.29	5.61	5.59	5.60	5.19
FRE	5.48	4.53	4.49	5.72	5.60
FTC	5.13	3.93	4.76	5.34	5.25
GCA *	4.76	4.60	4.99	4.26	4.52
GCY	5.75	6.06	6.03	6.06	5.62
GEO *	5.17	5.55	5.53	5.39	5.43
GOL *	4.52	4.69	4.61	4.31	4.60
GSC *	4.39	3.39	4.19	4.48	4.40
HAI	5.00	3.97	4.42	5.15	5.03
HAY	4.82	3.85	4.98	4.90	4.75
HET	5.02	4.96	5.20	4.91	5.38
HHM *	4.79	4.68	5.09	4.60	4.73
HNH	5.17	5.45	5.44	5.30	4.89
ISA	4.83	3.63	4.20	5.02	4.90
JAS	4.29	3.71	3.23	4.52	4.43
JCT *	4.23	4.15	4.19	4.29	4.60
KFO	5.17	5.33	4.23	5.40	5.32
KRC	4.85	3.74	4.26	5.06	4.97
LAR *	4.68	4.81	4.79	4.44	4.70
LAW *	4.73	4.58	4.64	4.78	4.40
LLA	4.88	4.07	3.94	5.12	5.04
LON *	4.62	4.65	4.77	4.71	4.79
LRA	4.76	4.76	4.92	4.59	3.95
LUB *	4.98	5.04	4.82	5.19	5.40
MDS	4.79	4.96	5.00	4.59	4.84
MHC *	4.78	4.14	3.65	5.03	4.94
MHS	4.95	5.13	5.31	4.36	4.75
MHT	4.57	4.42	4.46	4.75	4.49
MIM	5.21	5.40	5.38	5.57	4.88

Table 2 Cont.

MIN	4.59	4.52	3.32	4.84	4.71
MLF	4.52	4.85	4.89	4.45	4.26
MNN	4.71	4.79	4.78	4.70	5.03
MRG*	5.57	5.99	6.02	5.71	5.89
MWC*	4.55	3.44	4.40	4.70	4.62
NOL	5.19	5.33	5.53	5.13	5.28
OGD	4.87	5.21	5.19	5.14	4.84
ORV*	4.59	4.35	3.26	4.85	4.72
OXF	4.79	4.93	5.08	4.62	3.79
PAC	5.38	4.77	4.17	5.64	5.56
PAL*	4.87	5.19	5.17	5.17	4.77
PAS*	4.46	3.31	4.19	4.61	4.53
PCC	5.18	4.61	4.00	5.42	5.37
PCU	5.06	5.25	5.29	4.28	4.79
PHI*	5.32	5.67	5.64	5.59	5.37
PLM	4.55	3.55	4.63	4.65	4.54
PRS*	5.03	4.18	4.10	5.26	5.20
RCD	5.02	4.91	4.94	5.21	5.18
REN	4.70	4.44	3.44	4.90	4.79
ROL	4.47	4.46	4.57	4.29	3.43
RUT	4.54	4.32	4.18	4.21	4.39
RVR	4.55	3.23	4.11	4.68	4.55
SCC	5.46	4.35	3.94	5.71	5.65
SCP*	4.98	5.40	5.40	5.18	5.30
SEA	5.79	5.70	6.01	5.86	6.00
SFB	5.48	4.97	4.20	5.73	[illegible]
SFC	5.56	5.04	4.28	5.80	5.74
SHA	5.25	5.48	5.63	5.24	5.26
SLC*	4.81	5.04	4.99	4.04	4.57
SLM	5.03	5.10	5.20	4.81	3.78
SNC	5.73	4.60	5.66	5.86	5.86
SNM	4.49	4.73	4.57	4.48	4.38
SPO*	4.99	4.97	5.29	4.95	5.06
TFO*	3.75	3.57	4.05	3.66	3.50
TIN	4.55	3.71	3.79	4.69	4.57

Table 2 Cont.

TNP	4.33	3.76	3.62	4.34	4.31
TRY	5.31	5.63	5.62	5.61	5.15
TUC *	4.38	4.30	4.61	4.37	4.17
TUL *	4.71	4.57	4.66	4.73	4.46
TUM *	5.77	5.72	5.94	5.87	6.00
TYS	4.96	5.02	5.12	4.74	3.72
UBO *	3.96	4.23	4.26	3.38	3.68
UKI *	5.49	5.29	4.14	5.74	5.69
UVN	4.18	4.08	3.36	4.18	4.18
VIN	5.79	4.95	4.76	6.04	5.97
VIT	4.98	4.21	3.96	5.22	5.15
WDY *	4.27	3.19	3.54	4.46	4.37
WES *	4.85	5.08	5.06	5.20	4.54
WMO *	3.70	3.57	3.56	3.86	3.97
WTR	5.18	5.38	5.36	5.54	[illegible].84

***Stations** which regularly report for P.D.E.

Stations which have an average threshold magnitude, between 4.20 and 4.50, are grouped as average performance. These stations govern the network performance locally and regionally. They may be expected to contribute little to the total network performance for events at near regional distances (600 km to 1300 km) and beyond the limits of the regional zone. Ten stations which report regularly for P.D.E. fall within this group. Two additional stations which do not regularly report for P.D.E.--Socorro, New Mexico, and Tonopah, Nevada--may be classified within this group. These stations have peak magnification in excess of 200,000.

Stations which have an average threshold magnitude greater than 4.5 are considered low performance. They provide only local control governing the network capability. This group includes roughly 80% of all of the stations in the United States.

The above groupings provide a relative measure of the station contribution to the network performance for the entire United States. Consideration of the average station threshold magnitude for subsets of events reveals that low performance stations often contribute critical control in limited areas. The divisions between groups should not be considered perfectly rigid. Furthermore, the performance of stations varies within the limits of each group.

A more complete understanding of the expected station performance may be gained from consideration of the threshold magnitude versus distance curves of Appendix II. In the construction of these curves azimuthal effects on signal attenuation are not considered. Attenuation is assumed to be only a function of distance and corrections are applied for anomalous signal reception due to regional geological effects in the area of the station by means of the variable s/n.

5.3 Network Probability versus Magnitude

Network detection capability is conveniently displayed by curves relating the probability that a given magnitude of an array of events will be detected. In addition, such curves provide a means of comparing the capability of different sets of stations. The results for the array of events representing the entire United States are displayed in Figure 32 and are summarized in Table 3.

The set of all United States stations, the set of stations regularly reporting for P.D.E., the set of selected high gain stations, and the set of five array plus twenty-five WWNSS stations show comparable detection capability at the 100% probability level. Each of the sets of stations may be expected to detect essentially all events above $m_b = 4.2$ in the conterminous United States. As magnitude decreases, however, the set of all United States stations shows increasingly better relative detection capability. The average network threshold

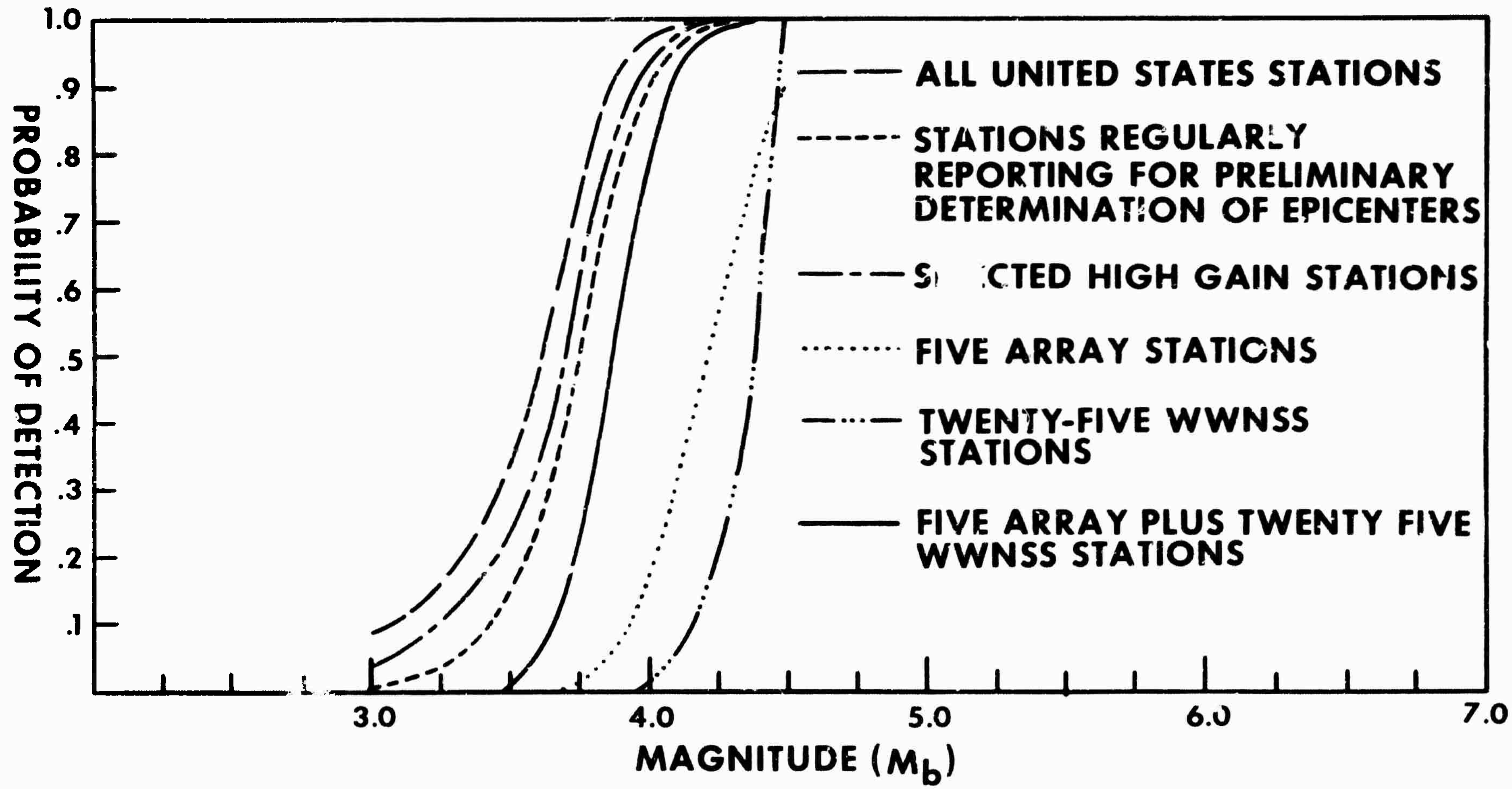


Figure 32. Average Network Detection Probability Versus Magnitude for the Set of Events Representing the Entire Conterminous United States.

TABLE 3
PERCENT OF EVENTS OF THE UNITED STATES GRID EXPECTED TO BE RECORDED BY AT LEAST FIVE STATIONS OF INDICATED SETS OF STATIONS

Magnitude m_b	All United States Stations (Percent)	Stations Reporting for PDE (Percent)	Selected Stations (Percent)	Five Array Stations (Percent)	Twenty-Five WWNSS Stations (Percent)	Array Plus WWNSS Stations (Percent)
3.0	9.1	1.3	3.9	0	0	0
3.1	11.5	1.9	6.0	0	0	0
3.2	14.4	3.0	8.6	0	0	0
3.3	18.0	5.0	12.0	0	0	0
3.4	25.3	8.4	16.7	0	0	0.3
3.5	34.4	14.4	23.4	0	0	1.3
3.6	47.9	24.2	33.5	0.3	0	5.4
3.7	66.1	39.4	49.8	1.0	0	16.6
3.8	83.2	60.0	70.2	2.8	0	35.8
3.9	93.1	79.4	85.6	7.5	0	58.8
4.0	97.5	90.8	94.1	16.0	1.7	79.0
4.1	98.9	95.5	97.8	29.2	5.6	92.1
4.2	100.0	98.5	100.0	47.0	16.7	98.5
4.3	100.0	100.0		65.3	36.7	100.0
4.4				78.4	59.5	
4.5				89.7	100.0	

magnitude ranges from 3.61 for the set of all United States stations to 3.88 for the subset of five array plus 25 WWNSS stations. Divergence continues with decreasing magnitude.

The twenty-five WWNSS stations have the highest average network threshold magnitude (4.38) of the five subsets of stations considered. The probability of detection, however, increases rapidly with increasing magnitude and a 100% probability of detection is predicted for events of magnitude 4.5. Conversely, the subset of five array stations has an average network threshold of 4.23, but is predicted to detect only 89.7% of magnitude 4.5 earthquakes. The results illustrate that station density becomes increasingly important in determining the network capability as the magnitude decreases, provided the high performance stations are included in each station set. However, since the stations have variable detection capabilities, an increase in station density does not necessarily result in a corresponding increase in network detection capability.

In order to obtain a more complete evaluation of the network detection capability in limited areas of known high seismicity, subsets of events representative of southern California, northern California, the eastern Basin and Range, and southeast Missouri have been evaluated. The results are displayed on Figures 33 to 36 and summarized in Tables 4 to 7. In all of the four areas the set of all United States stations has the

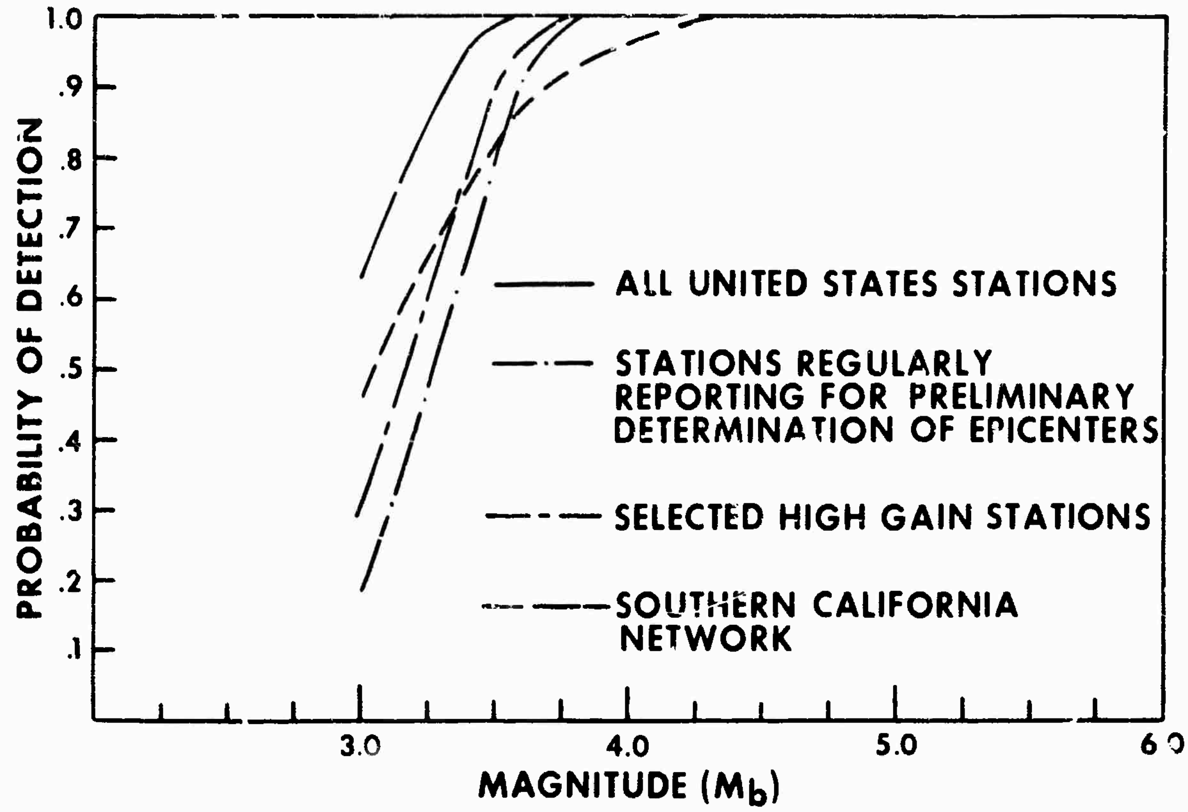


Figure 33. Average Network Detection Probability Versus Magnitude for the Subset of Events Representing Southern California.

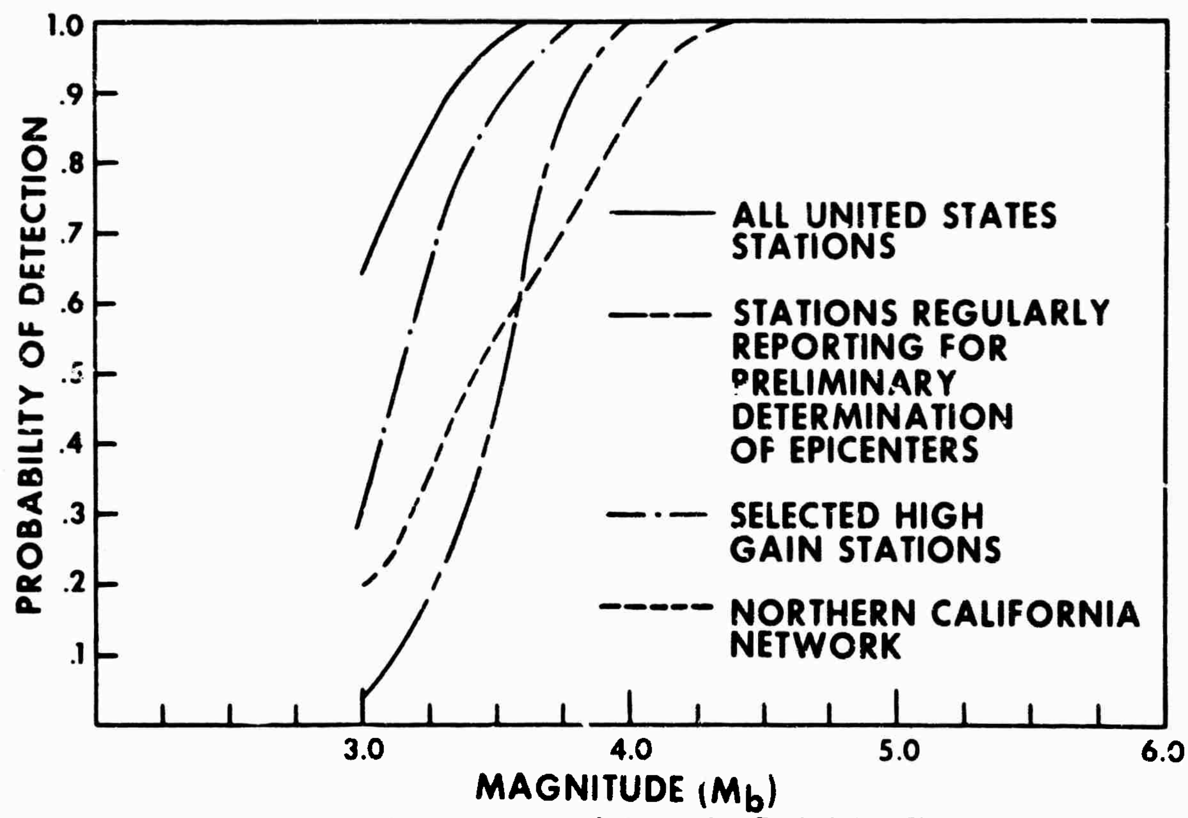


Figure 34. Average Network Detection Probability Versus Magnitude for the Subset of Events Representing Northern California.

TABLE 4

PERCENT OF EVENTS OF THE SOUTHERN CALIFORNIA GRID EXPECTED TO BE RECORDED BY AT LEAST FIVE STATIONS OF INDICATED SETS OF STATIONS

Magnitude m_b	All United States Stations (Percent)	Southern California Stations (Percent)	Stations Reporting for PDE (Percent)	Selected Stations (Percent)
3.0	71.0	46.2	20.0	32.4
3.1	80.0	54.2	28.3	41.7
3.2	88.9	62.6	40.4	52.5
3.3	95.1	69.5	53.7	65.9
3.4	100.0	74.6	68.7	80.6
3.5		80.4	82.1	89.3
3.6		87.0	91.3	95.7
3.7		92.1	97.4	100.0
3.8		93.5	100.0	
3.9		94.3		
4.0		95.2		
4.1		95.4		
4.2		100.0		

TABLE 5
PERCENT OF EVENTS OF THE NORTHERN CALIFORNIA GRID EXPECTED TO BE RECORDED BY AT LEAST FIVE STATIONS OF INDICATED SETS OF STATIONS

Magnitude m_b	All United States Stations (Percent)	Northern California Stations (Percent)	Stations Reporting for PDE (Percent)	Selected Stations (Percent)
3.0	64.3	19.7	4.5	31.8
3.1	73.2	24.4	8.9	43.9
3.2	80.4	32.0	14.4	53.6
3.3	87.0	41.6	22.1	61.0
3.4	91.8	49.2	31.1	68.9
3.5	97.9	54.2	45.8	79.2
3.6	100.0	57.9	63.2	89.5
3.7		63.3	80.0	96.7
3.8		73.9	91.3	100.0
3.9		78.9	94.7	
4.0		86.7	100.0	
4.1		91.7		
4.2		100.0		

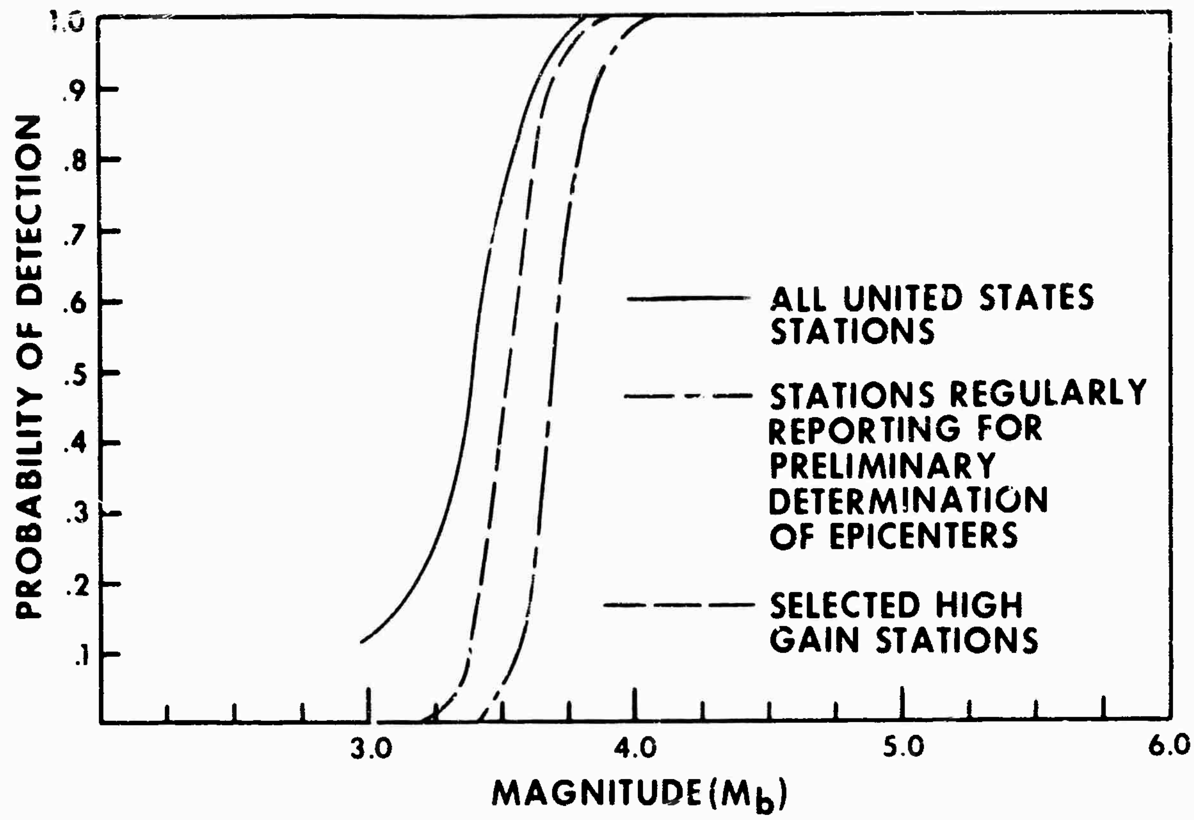


Figure 35. Average Network Detection Probability Versus Magnitude for the Subset of Events Representing the Eastern Basin and Range.

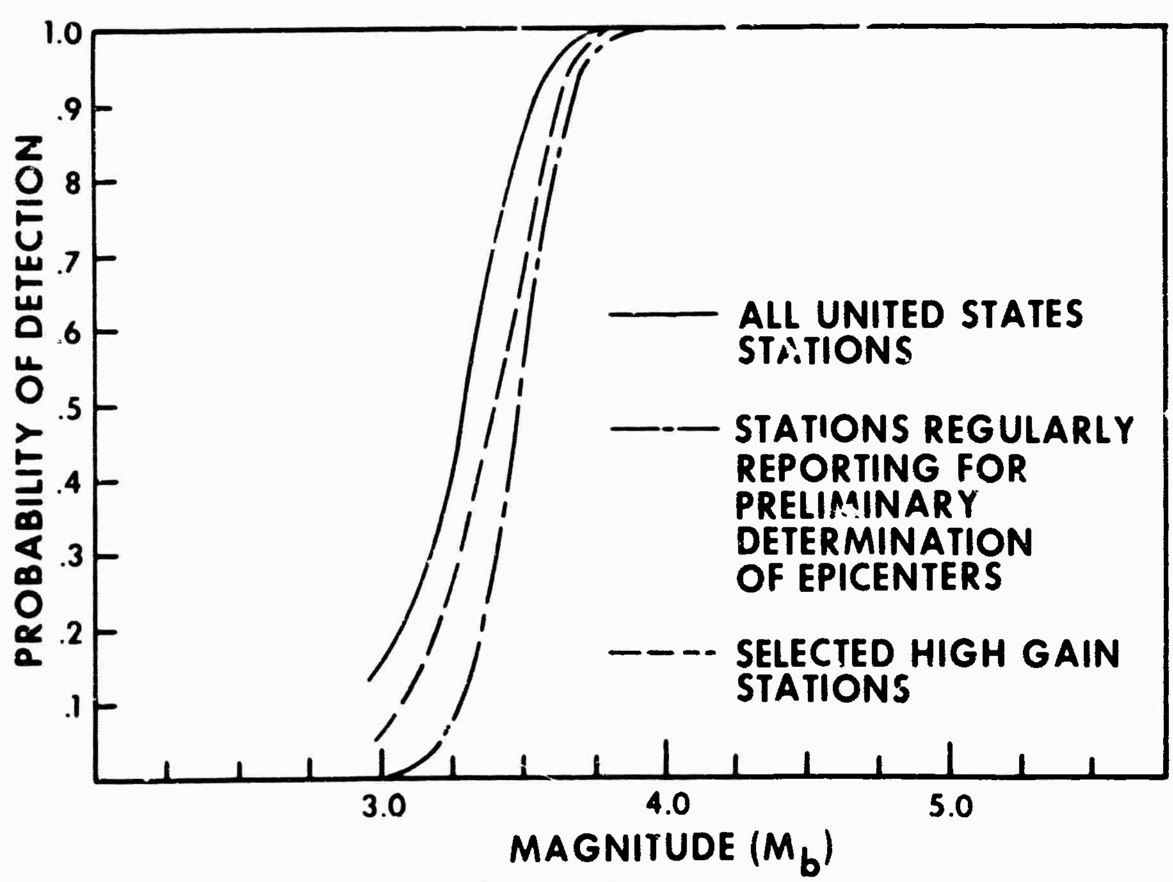


Figure 36. Average Network Detection Probability Versus Magnitude for the Subset of Events Representing Southeast Missouri.

TABLE 6
PERCENT OF EVENTS OF THE EASTERN BASIN AND RANGE GRID EXPECTED TO BE RECORDED BY AT LEAST FIVE STATIONS OF INDICATED SETS OF STATIONS

Magnitude m_b	Total United States Stations (Percent)	Stations Reporting for PDE (Percent)	Selected Stations (Percent)
3.0	16.4	0.6	7.4
3.1	24.5	1.8	13.6
3.2	34.8	5.2	21.3
3.3	50.7	14.0	32.1
3.4	70.8	30.4	47.8
3.5	86.0	52.9	67.8
3.6	94.5	75.8	85.7
3.7	98.5	91.2	97.1
3.8	100.0	98.0	100.0
3.9		100.0	

TABLE 7
PERCENT OF EVENTS OF THE SOUTHEAST MISSOURI GRID
EXPECTED TO BE RECORDED BY AT LEAST [illegible] STATIONS
OF INDICATED SETS OF STATIONS

Magnitude m_b	Total United States Stations (Percent)	Stations Reporting for PDE (Percent)	Selected Stations (Percent)
3.0	12.0	0	0
3.1	14.8	0	0
3.2	20.7	0	0
3.3	33.9	0	3.2
3.4	55.3	0	12.8
3.5	72.2	5.6	38.9
3.6	88.9	22.2	70.4
3.7	95.2	47.6	90.5
3.8	100.0	75.0	100.0
3.9		91.7	
4.0		100.0	

lowest average network threshold magnitude. In both southern and northern California, this magnitude is well below the lowest magnitude (m_b = 3.0) considered in the analysis, while in the eastern Basin and Range it is 3.3 and in southeast Missouri it is 3.4.

For events of magnitude less than m_b = 3.5 in California, the local station networks show better detection capability than the stations which report regularly for P.D.E. In all of the four areas, the set of stations selected for gain and geographic distribution show improved detection capability over the set of stations which now regularly report for P.D.E.

5.4 Spatial Presentation of Network Detection Capability

The network probability versus magnitude curves of the preceding section display the expected network performance for a set of events representing a particular geographic region. Detailed presentation of the network detection capability by this method would require the construction of a large number of such curves depending on the detail desired. A more convenient method by which the spatial variation of the network capability is displayed in detail is to plot the magnitude for each epicenter location at a constant level of network probability. This has been done for the network threshold probability level and for the 100% probability level for the

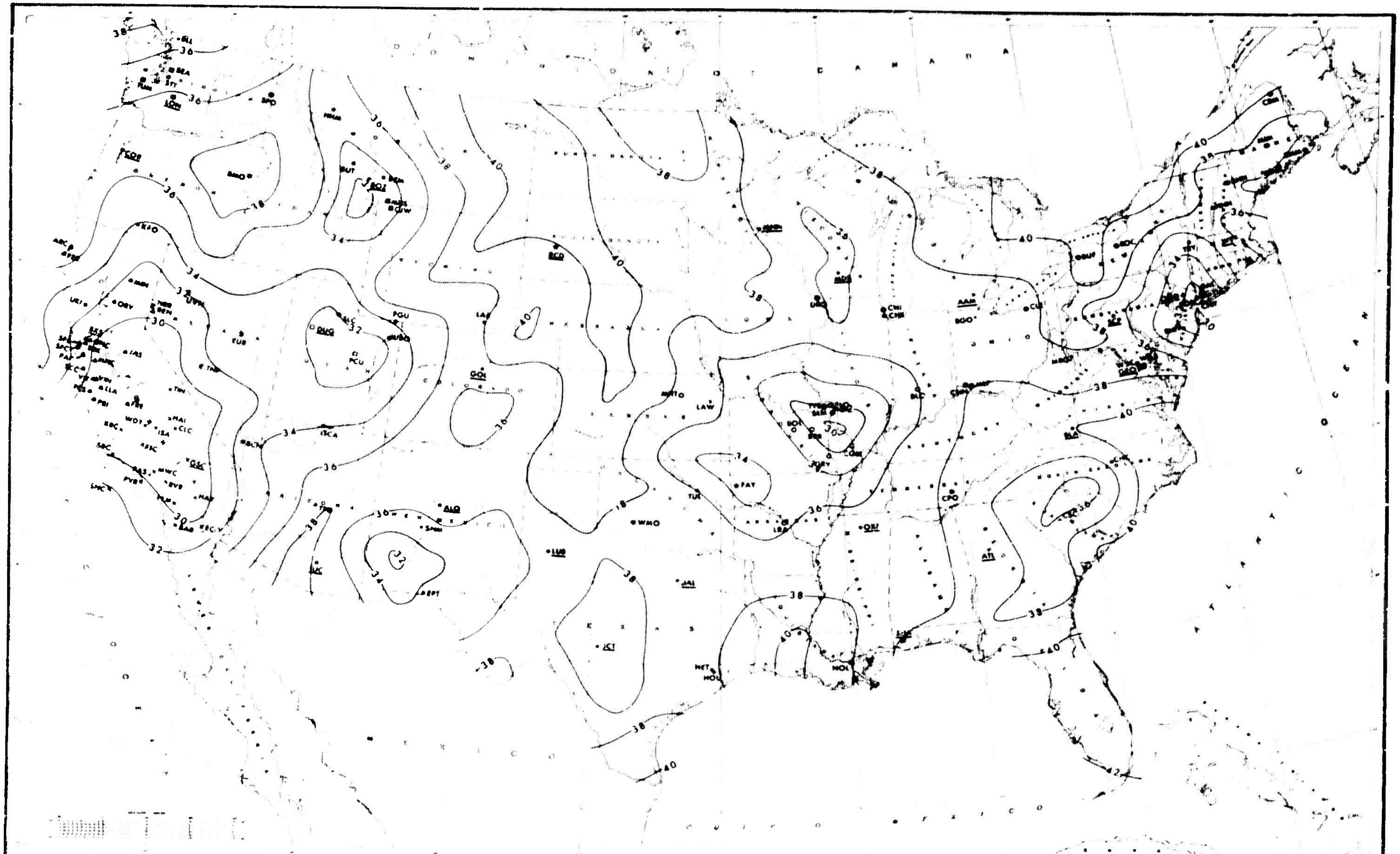


Figure 37. Network Threshold Magnitude for the Set of All United States Seismograph Stations.

entire United States network of stations. The contoured results are displayed in Figures 37 and 38. For comparison, threshold probability maps were prepared for two subsets of stations. The first subset consists of the stations which regularly report for P.D.E. The second subset consists of five array stations (Figures 39 and 40). For each presentation the stations used are shown.

Figure 37 displays several interesting features. Only two limited areas west of the Rocky Mountain front, south-central Arizona and northeastern Oregon, have network threshold magnitudes greater than the average network threshold magnitude for the entire United States (see Figure 32). The highest network threshold magnitudes in the interior are in the central plains states. In detail the network threshold magnitude pattern is due to three conditions: (1) local station density; (2) local stations combined with high performance stations at regional distances: and (3) high performance stations alone.

The areas which display the lowest network threshold magnitudes correlate well with local dense station coverage. Examples are the California, Nevada, and Utah area, the Yellowstone Park area, the southeast Missouri area, and the southern New York area. In these areas the network threshold magnitude is well below the station threshold magnitudes of the high performance stations. Earthquakes occurring in these areas

which have magnitudes near the network threshold magnitude will generally be recorded only by local stations.

Local stations combine with high performance stations at regional distances to produce below average network threshold magnitudes in three areas; central Colorado, central Wisconsin, and southern North Carolina. The low of central Colorado is due to the combined detection capabilities of the local station, GOL, and the high performance stations ALQ, UBO, TFO, and CPO, at near regional and regional distances. A similar condition produces the low of central Wisconsin. Here two local stations, MDS and DBQ, combine with the high performance stations, TFO, BMO, and WMO, to provide the necessary control for epicenter location. The low network threshold magnitude values near the North Carolina-South Carolina border are a result of the combined capabilities of three local stations, CSC, CHC, and BLA, and two high performance stations, CPO and WMO, at near regional and regional distances. The low network threshold magnitude values centered in southwest New Mexico are due to a different condition. This is the optimum recording area for the high and average performance stations of Arizona and New Mexico.

The network capability in the central plains states is primarily due to the high performance stations. Consequently, the values are not significantly altered when the near stations are excluded.

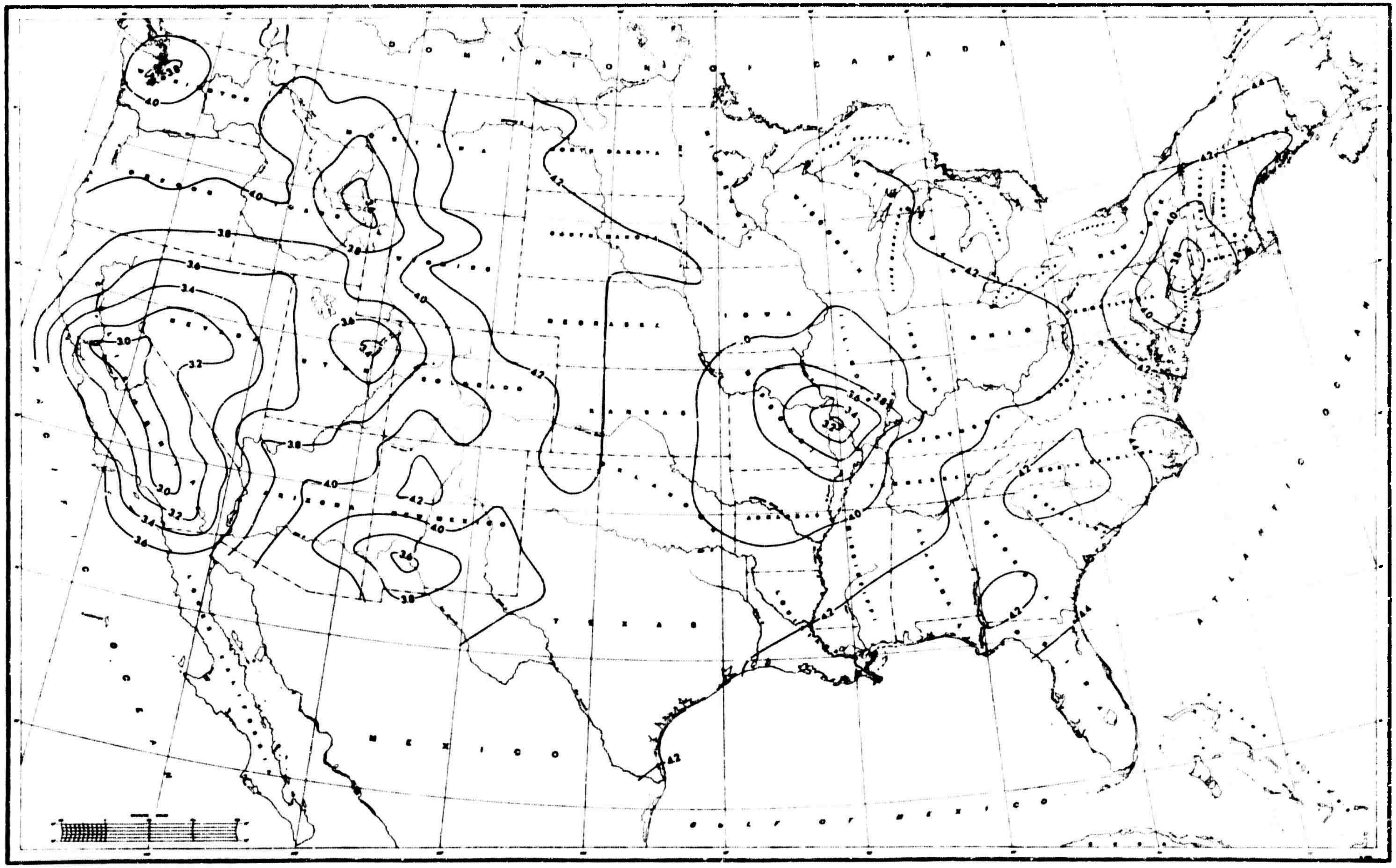


Figure 38. Magnitude for 100 Percent Probability of Detection by at Least Five Stations of the Total Set of All United States Seismograph Stations.

Figure 38 represents the 100% network probability level for the set of all United States stations. Since the station distribution is unchanged, the overall pattern is not significantly altered from that of Figure 37. However, with the exception of central California, the level is everywhere increased from 0.2 to 0.6 units of magnitude.

Figure 39 is a display of the network threshold magnitude for the subset of stations which regularly report for P.D.E. The overall pattern as well as the maximum threshold level is not significantly altered from that displayed in Figure 37. Again, the lowest values are generally in the western United States. The significant difference is in detail. A much reduced network capability is apparent along the Pacific coast and in the mountain states of the western interior. East of the Rocky Mountain front, the network capability is significantly reduced in the southeast Missouri and southern New York areas. In areas where the network capability is primarily due to the high performance stations, it is essentially unchanged.

For further comparison a network threshold magnitude map was prepared for the five array stations. These are, in terms of their predicted contribution to the total network capability, the best stations of the network. Furthermore, they are located so as to provide broad coverage. The results are displayed in Figure 40.

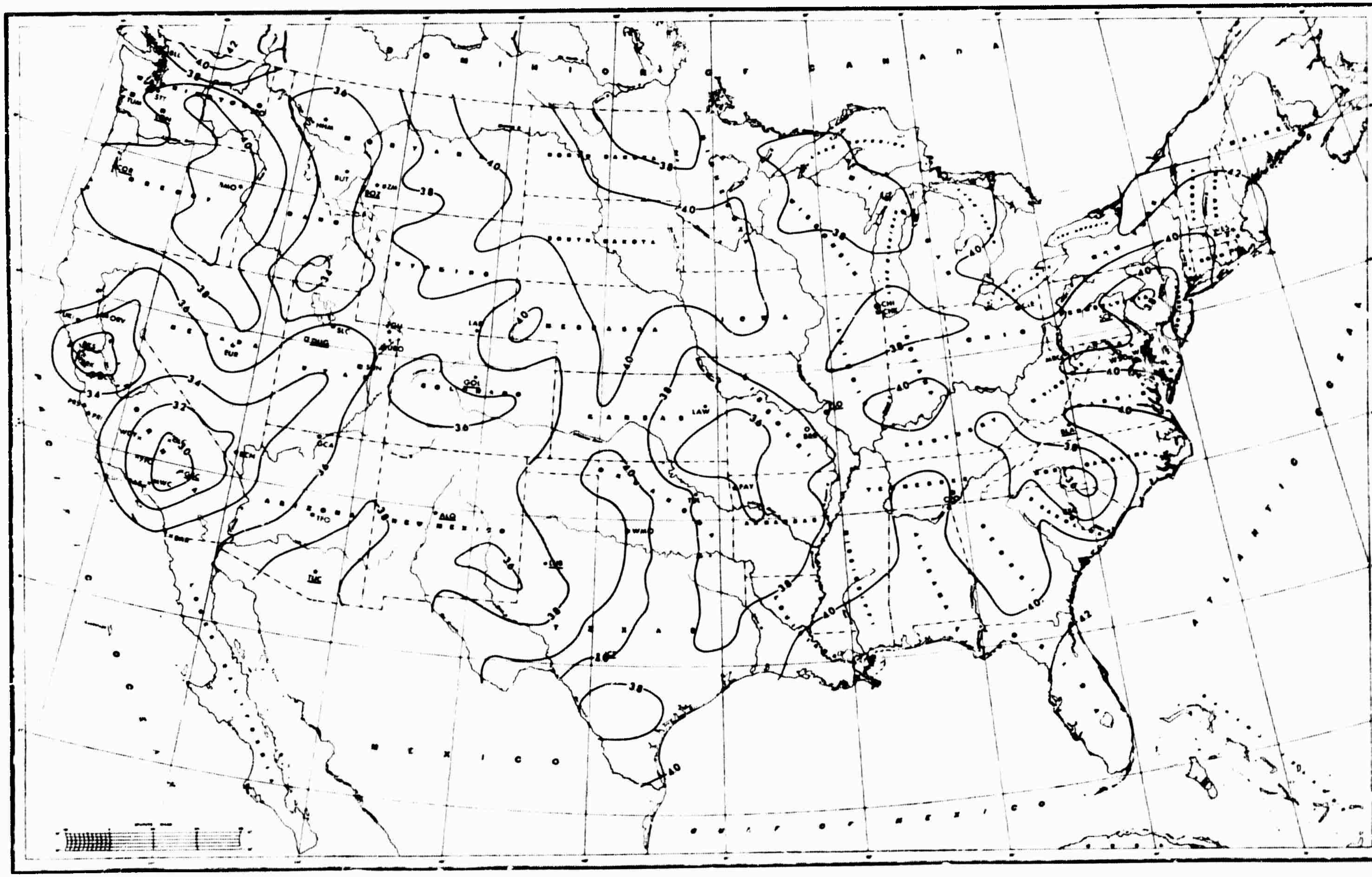


Figure 39. Network Threshold Magnitude for the Subset of Stations which Report Regularly for P.D.E.

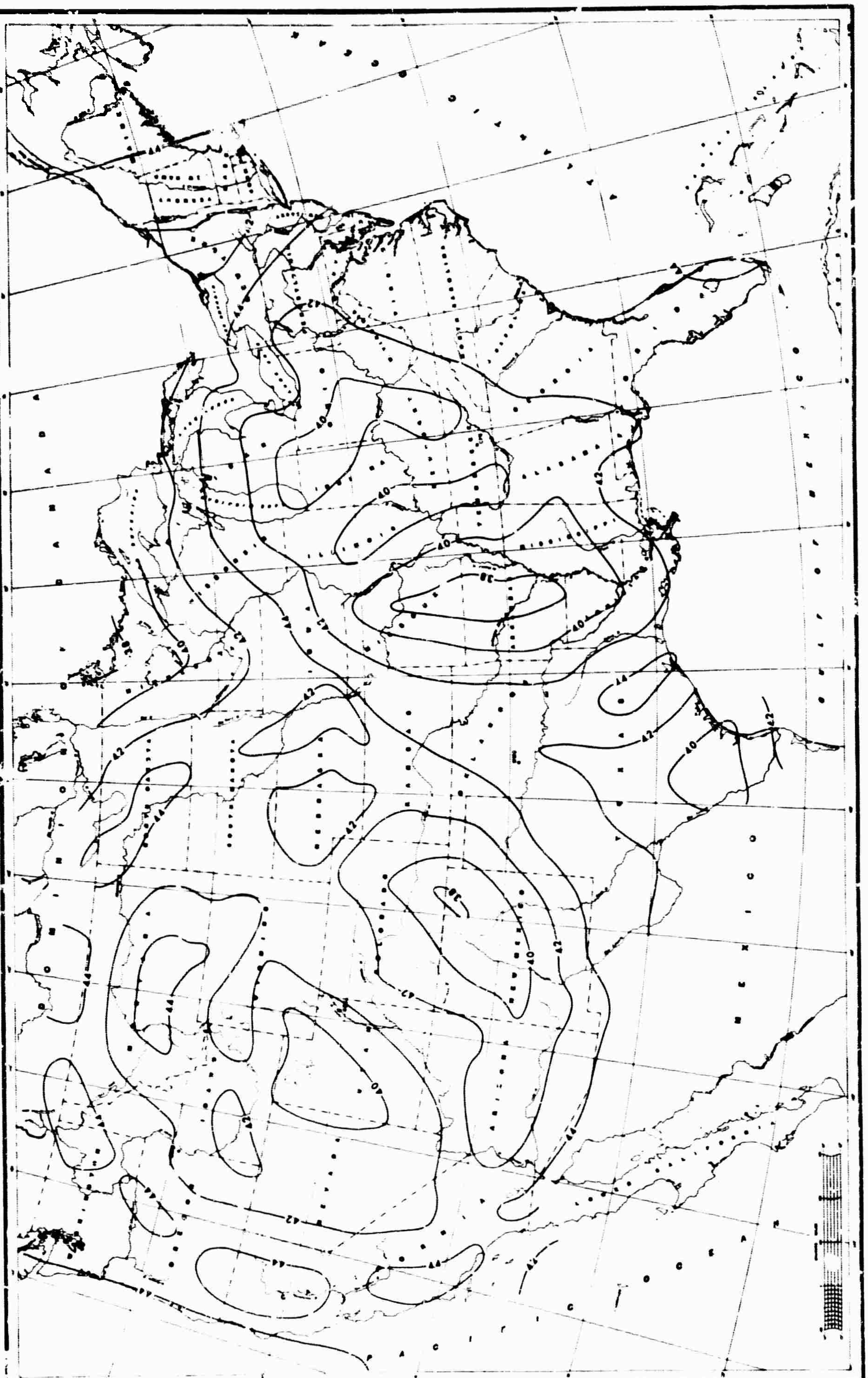


Figure 40. Network Threshold Magnitude for the Subset of Five Array Stations.

It may be observed that the highest network threshold values occur in concentric patterns corresponding to the shadow zone for each station. As it is specified that all five of the stations must detect each event, the network capability at any position is equivalent to the poorest station capability. More important, however, are the network threshold values in the central plains area. The values here are essentially equivalent to those for the set of all United States stations at the 100% probability level. Moreover, they approach the threshold magnitude level for the set of all United States stations. Similarly, in the southeastern states, the network threshold magnitudes for the five array stations are essentially the same as the 100% probability level for the set of all United States stations.

5.5 Accuracy of Hypocenter Determination and Quality of Station Distribution

In the preceding sections, attention has been given only to the detection of an event by at least five stations of various sets of stations. Experience has shown that detection by five stations does not assure a hypocenter location by the least square method. In the case of shallow earthquakes, with which we must be concerned in the United States, depth of focus is the most difficult hypocentral parameter to determine.

To obtain a solution for these events the depth generally must be restrained and a solution obtained for the origin time and epicenter.

The difficulty is due to the least squares method which depends on the rate of change of travel time with depth for depth determination. Thus accurate depth determinations for shallow earthquakes in the earth's crust require station control near enough the epicenter to lie on the curved portion of the travel time curve. For these events, therefore, accurate focal depth determination requires high density of stations--higher than is available in most areas. Difficulty also arises due to anomalous velocities which are not accounted for in the travel time curves. The least squares method requires that errors be normally distributed with respect to their expected value. Thus anomalous velocities which result in departures from this normal distribution are reflected in errors in the hypocenter location.

The general problem of error determination in earthquake location involves statistical treatment of recording station residuals. Such a treatment for the case of hypothetical epicenters requires consideration of systematic errors in travel time curves and regional travel time anomalies. These are

generally not well known. One situation bearing on the accuracy of epicenter determination which can easily be treated for hypothetical epicenters is the distribution of recording stations. Of particular interest in the present study is the case of a few recording stations possibly badly distributed around the epicenter.

The method of determining the quality of station coverage for an epicenter location described by Flinn (1964) has been used for this study. The resulting "distribution factor" which is normalized between zero and one, is a measure of the azimuthal distribution of the predicted recording stations about the epicenter location. Distribution factors for the 100% probability of detection by the total United States set of seismograph stations (Figure 38) are displayed in Figure 41.

A distribution factor value of unity means that the predicted recording stations are uniformly distributed around the epicenter. A value of 0.7 or greater means that recording stations are rather evenly distributed in all four quadrants. Values between 0.4 and 0.6 usually imply a good distribution of recordings in at least three quadrants, often with control in the fourth quadrant. Values of 0.4 or less imply heavy weighting of recording stations in one quadrant, often with no control in one or more of the remaining quadrants.

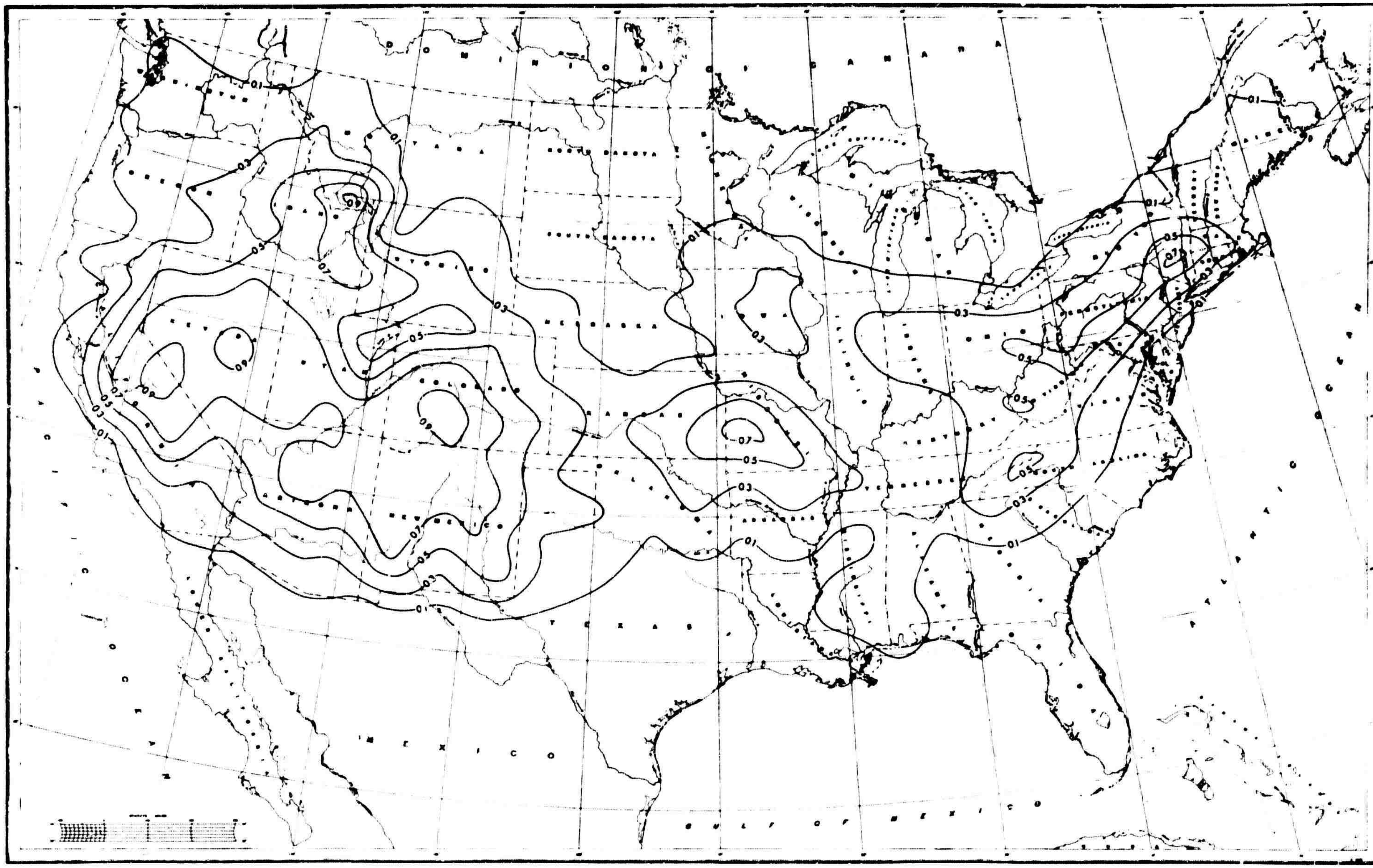


Figure 41. Normalized Azimuthal Distribution of Stations Expected to Detect an Event at 100 Percent Network Probability Level as a Function of Geographic Position.

For the magnitude distribution of Figure 38, recording stations for epicenters within the areas enclosed by the 0.7 contours of Figure 41 may be expected to be evenly distributed among the four quadrants. These epicenters should have the most accurate locations. Epicenters in the areas inclosed by the 0.5 contours may be expected to have a good distribution of recording stations but control will usually be poor in one quadrant. Epicenters within these areas should have good accuracy. In areas outside of the 0.3 contours events will usually be strongly weighted with recordings in one quadrant and have no recordings in one of the remaining three quadrants. In these areas epicenter locations may be expected to be poor.

From the above considerations station density becomes more important than was implied from consideration of network detection alone. It was pointed out in Section 5.3 that the detection capability of the entire United States station network at the 100% probability level could be accomplished using about one half of the total number of stations. However, the above results suggest that the accuracy of hypocenter determination will be much reduced.

6. Comparison of Predicted Network Capability With Actual Network Performance

The geographic display of earthquakes on Figures 2 to 7 shows good correlation between areas which have large numbers

of earthquakes with magnitudes less than 4.0 and the areas of low network threshold magnitude on Figure 39. The lowest magnitude earthquakes are reported from east-central Idaho and southern Nevada. These two areas comprise essentially all of the reported earthquakes of magnitude less than 3.5. The exception is California, where earthquakes of magnitudes less than 4.0 are not generally reported on P.D.E. cards.

A more complete comparison of the predicted and actual network performance has been gained by using 344 actual earthquakes reported on P.D.E. cards during 1963 as input data to the network capability program. The predicted results are summarized in comparison with a summary of the actual station performance in Table 8. Columns 1 and 2 show the number of events predicted to be recorded at each station and the percentage of the total. Columns 3 and 4 show the actual number of recordings reported and the percentage of the total. The last column shows the average station threshold magnitude for the entire set of 344 events.

A comparison of the actual and predicted network performance must take into consideration the completeness of seismogram analysis and subsequent reporting of data for P.D.E. For a majority of the stations this is difficult to evaluate.

The stations which are operated by the Coast and Geodetic Survey entirely or on a cooperative basis may be expected to provide the best basis of comparison. Seismograms from these stations are generally available for review concurrent with the preliminary determination of epicenters. Thus, significant readings are less likely to be missed in the process of seismogram analysis.

Using these stations (see Figure 18) as a basis of comparison, it is seen in Table 8 that all except four, ALQ, BOZ, RCD, and TUC, actually reported an equal or larger number of the events that was predicted. Of these four stations, RCD, was inoperative throughout the year, and BOZ was operative for only five months. In terms of numbers of events reported, EUR showed the best performance, having reported 86.5 percent of the 344 events located for P.D.E. as opposed to a predicted 70.9%. Thus, if these stations are representative of the entire network, provided complete analysis of the seismograms and reporting of the data is achieved, the predicted network capability at the threshold level is conservative.

Of the 51 stations which report regularly for P.D.E., 28 reported a larger percentage of the events than was predicted, while 21 reported fewer than were predicted. Two stations

TABLE 8

COMPARISON OF PREDICTED STATION
PERFORMANCE WITH 1963 REPORTS FOR
PRELIMINARY DETERMINATION OF EPICENTERS

Station	Predicted Number	Predicted Percentage	Reported Number	Reported Percentage	Average Threshold Magnitude
AAM	10	2.91	2	0.58	4.98
ALQ*	129	37.50	70	20.34	4.37
ARC	11	3.20	0	0	5.84
BAR*	112	32.56	19	5.41	4.49
BCN*	91	26.45	132	37.61	4.72
BKS*	29	8.43	35	9.97	5.10
BLA*	8	2.33	9	2.56	5.11
BLL	22	6.40	0	0	5.13
BLO	28	8.14	7	1.99	4.75
BMO*	290	84.30	285	82.85	4.11
BOZ*	203	59.01	105	29.91	4.32
BRK*	21	6.10	15	3.70	5.48
BRR	35	10.17	0	0	4.69
BUT*	154	44.77	153	44.48	4.52
CBM	9	2.62	2	0.58	5.18
CGM	31	9.01	3	0.87	4.75
CHC*	3	0.87	6	1.71	5.37
CHI*	1	0.29	3	0.87	5.65
CLC*	110	31.98	17	4.84	4.59
CLE*	0	0	2	0.58	5.66
CNC	19	5.52	6	1.74	5.54
CNY	0	0	0	0	6.02
COR*	12	3.49	13	3.70	5.44
CPO*	192	55.81	84	19.37	4.20
CSC*	3	0.87	6	1.74	5.36
DAL	13	3.87	3	0.87	4.99
DBQ	10	2.91	0	0	5.00
DUG*	223	64.83	70	19.94	4.19
EMM	1	0.29	3	0.87	5.65
EUR*	244	70.93	303	86.32	4.16
FAY*	19	5.52	23	6.55	4.89
FGU*	72	20.93	129	36.75	4.54
FLO*	35	10.17	11	3.13	4.67
FOR	3	0.87	2	0.58	5.60
FRE	22	6.40	7	1.99	5.49
FTC	52	15.12	3	0.85	5.13
GCA*	46	13.37	77	21.94	4.76
GCY	0	0	1	0.29	6.06
GEO*	4	1.16	3	0.87	5.46
GOL*	59	17.15	85	23.93	4.66

Table 8 con't

GSC *	119	34.59	28	7.98	4.57
HAI	72	20.93	2	0.58	5.02
HAY	81	23.55	13	3.70	4.85
HET	17	4.94	0	0	4.99
HHM *	54	15.70	139	39.60	4.67
HNH	6	1.74	0	0	5.48
ISA	81	23.55	2	0.60	4.90
KRC	68	19.77	4	1.14	4.93
LAR *	52	15.12	67	19.09	4.69
LAW *	40	11.63	27	7.69	4.67
LLA	35	10.17	11	3.20	4.98
LON *	66	19.19	15	4.36	4.69
LRA	35	10.17	1	0.29	4.70
LUB *	8	2.33	22	6.27	5.09
MDS	20	5.81	0	0	4.78
MHC *	37	10.76	34	9.88	4.90
MHT	68	19.77	3	0.87	4.58
MIM	5	1.45	3	0.87	5.47
MIN	62	18.02	8	2.33	4.68
MNN	24	6.98	1	0.29	4.76
MRG *	1	0.29	4	1.14	5.82
MWC *	101	29.36	3	0.87	4.64
OGD	9	2.62	1	0.29	5.17
ORV *	62	18.02	95	27.07	4.70
PAC	21	6.10	0	0	5.46
PAL *	9	2.62	4	1.16	5.18
PAS *	107	31.10	53	15.41	4.57
PCU	33	9.59	7	2.03	4.87
PHI *	1	0.29	1	0.29	5.62
PLM	103	29.94	14	4.07	4.52
PRS *	29	8.43	40	11.62	5.12
RCD	14	4.07	0	0	5.09
REN	53	15.41	0	0	4.72
ROL	95	27.62	5	1.45	4.39
RVR	102	29.65	14	4.07	4.64
SCC	18	5.23	11	3.20	5.54
SCP *	7	2.03	7	2.03	5.29
SEA	4	1.16	8	2.33	5.83
SFB	19	5.52	1	0.29	5.56
SFC	19	5.52	6	1.74	5.63
SHA	3	0.87	0	0	5.41
SLC *	73	21.22	93	27.03	4.53
SLM	20	5.81	13	3.78	4.94
SNC	11	3.20	0	0	5.61
SPO *	27	7.85	26	7.56	4.90
TFO *	218	63.37	193	56.10	4.18

Table 8 con't

TIN	98	28.49	10	2.91	4.64
TRY	4	1.16	0	0	5.61
TUC *	106	30.81	79	22.97	4.52
TUL *	43	12.50	41	11.92	4.62
TUM *	5	1.45	6	1.74	5.82
UBO *	280	81.40	285	82.85	4.12
UKI *	19	5.52	19	5.52	5.58
VIN	14	4.07	2	0.58	5.84
VIT	31	9.01	11	3.20	5.08
WDY *	[illegible]	35.17	15	4.36	4.49
WES *	[illegible]	3.49	3	0.87	5.15
WMO *	[illegible]	84.59	116	33.72	4.11
WTR	[illegible]	1.74	0	0	5.45

*Stations which regularly report for P.D.E.

were not operational. It is not known to what degree incomplete reporting of data influence these results. However, the overall predicted network capability is probably somewhat conservative.

7. Conclusions

If complete reporting of data from all stations in the United States is achieved, it can be anticipated that the existing seismograph station network will have a 0.95 probability of detecting all earthquakes in the United States as small as magnitude 4.0 with at least five stations. For local areas of high station density, this value may extend below magnitude 3.0. The magnitude corresponding to the 0.5 probability is 3.6. The 51 stations which regularly report for P.D.E. have a 0.87 probability of detecting all earthquakes in the United States as small as magnitude 4.0. Fifty-seven stations selected for geographic distribution and gain have a 0.92 probability of detecting all earthquakes in the United States as small as magnitude 4.0. Thus, for earthquakes as small as magnitude 4.0, the 57 selected stations have a capability approximately equal to that of the entire network of 116 stations.

The primary network control is provided by eight high performance stations. Twelve stations provide regional control, while 96 stations provide primarily local control. In areas of very low station density, the network capability is equivalent

to the capability of the high performance stations alone. In some areas, the network capability is due to the combined capabilities of local stations and high performance stations at regional distance. In other areas, notably California, southwest Montana, southeast Missouri, and southern New York, the network capability is primarily a function of station density. In these areas earthquakes with magnitudes near the network threshold level may be expected to be recorded only locally.

Although about 80% of the stations contribute to the network detection capability only locally, they provide valuable local control for the determination of hypocenters. In terms of the azimuthal distribution of predicted recording stations earthquakes in the western mountain region, east central Missouri, and southern New York should have the best locations.

Comparisons of predicted station performance with actual reports for P.D.E. during 1963 indicate that the predicted network capability may be somewhat conservative.

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APPENDIX I

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APPENDIX II

STATION INSTRUMENTATION

Station Location	Abbreviation	Coordinates N. Lat.	Coordinates W. Long.	Station Instrumentation*	T_o (sec)	T_g (sec)	Magnification
Ann Arbor, Michigan	AAM	42°17'59"	83°39'22"	3 Benioff 100 kg, N, E, Z	1.0	0.75	[illegible],000
				3 Sprengnether, N, E, Z	30	100	750
Albuquerque, New Mexico	ALQ	34°56'30"	106°27'30"	3 Benioff 100 kg, N, E, Z	1.0	0.75	400,000
				3 Sprengnether, N, E, Z	30	100	3,000
Arcata, California	ARC	40°52'36"	124°04'30"	1 Benioff 15 kg, Z	1.1	0.2	5,870
				2 Wood-Anderson, N, E	0.8		2,800
Atlanta, Georgia	ATL	33°26'00"	84°20'15"	3 Benioff 100 kg, N, E, Z	1.0	0.75	100,000
				3 Sprengnether, N, E, Z	30	100	6,000
Barrett, California	BAR	32°40'48"	116°40'18"	1 Benioff 100 kg, Z	1.0	0.2	60,000
Boulder City, Nevada	BCN	35°38'51"	114°50'02"	1 Benioff M.C., Z	1.12	0.55	35,000
Bowling Green, Ohio	BGO	41°22'41"	83°39'33"	1 Sprengnether S.P., Z	1.5	1.5	3,000
Berkeley, California	BKS	37°56'48"	122°14'06"	3 Benioff 100 kg, N, E, Z	1.0	0.75	25,000
				3 Sprengnether, N, E, Z	30	100	3,000
				2 Wood-Anderson, N, E	0.8	-	2,800
				1 Benioff 14 kg, Z	1.0	0.2	45,600
Blacksburg, Virginia	BLA	37°12'40"	80°25'14"	3 Benioff 100 kg, N, E, Z	1.0	0.75	50,000
				3 Sprengnether, N, E, Z	30	100	3,000
Bloomington, Indiana	BLO	39°11'20"	86°30'15"	1 Benioff 14 kg, Z	1.0	1.0	28,000
				1 Benioff 14 kg, N	1.0	1.0	24,000
				1 Benioff 14 kg, E	1.0	1.0	66,000
				3 Sprengnether, N, E, Z	15	90	

Bozeman, Montana	BOZ	45°36'00"	111°38'00"	3 Benioff 100 kg, N, E, Z	1.0	0.75	200,000
				3 Sprengnether, N, E, Z	30	100	3,000
Berkeley, California	BRK	37°52'24"	122°15'36"	1 Benioff 100 kg, Z	1.0	0.8	Visible
				2 Wood-Anderson, N, E	0.8	-	100
				1 Galitzin-Wilip, Z	12	12	651
				1 Galitzin-Wilip, E	12	12	823
				1 Galitzin-Wilip, N	12	12	1,082
				1 Benioff 100 kg, Z	1.0	0.2	18,000
				1 Benioff 100 kg, Z	1.0	0.2	2,400
				1 Press-Ewing, Z	15	30	2,200
				1 Press-Ewing, N45°W	45	300	650
Butte, Montana	BUT	46°00'48"	112°33'48"	1 Wood-Anderson, N	0.8	-	2,800
				1 Wilson-Lamison, N	8.0	3.75	-
				1 Wilson-Lamison, E	8.0	3.97	-
				1 Benioff M.C., Z	1.13	0.5	25,000
Caribou, Maine	CBM	46°55'57"	68°07'15"	3 Benioff 100 kg, N, E, Z	1.0	0.8	-
Cape Girardeau, Missouri	CGM	37°19'00"	89°32'00"	1 Benioff, Z	1.0	1.0	-
				2 Sprengnether, N, E	20	90	-
Chapel Hill, North Carolina	CHC	35°55'00"	79°03'00"	1 Wilson-Lamison, Z	1.3	1.8	25,000
				1 Sprengnether, N	5.5	6.95	5,000
				1 Sprengnether, E	5.2	5.28	5,000
Chicago, Illinois	CHI	41°54'00"	87°38'00"	1 Sprengnether, Z	1.0	1.0	-
				1 Sprengnether, N	14	14	-
				1 Sprengnether, E	14	7	-
Canyon Junction, Wyoming	CJW	44°44'06"	110°29'24"	1 Sprengnether, Z	1.09		-
China Lake, California	CLC	35°49'00"	117°35'48"	1 Benioff 100 kg, Z	1.0	0.2	60,000
Cleveland, Ohio	CLE	41°29'28"	81°31'52"	1 Sprengnether, E	18.8	18.8	1,800
				1 Sprengnether, N	18.2	18.2	1,000
				1 Sprengnether, E	1.5	1.5	1,400
				1 Sprengnether, N	1.4	1.4	1,400
				1 Benioff, Z	1.0	6.0	9,100
				1 Sprengnether, Z	1.3		Visible

Concord, California	CNC	37°58'06"	122°04'18"	1 Benioff 100 kg, Z	1.0	0.2	18,000
City College, New York	CNY	40°49'18"	73°57'12"	1 Sprengnether, Z	2.0	2.2	2,000
				1 Sprengnether, N	6.0	6.8	3,000
				1 Sprengnether, E	6.0	7.4	3,000
Corvallis, Oregon	COR	44°35'08"	123°18'11"	3 Benioff 100 kg, N, E, Z	1.0	0.75	25,000
				3 Sprengnether, N, E, Z	30	100	1,500
Columbia, South Carolina	CSC	34°00'00"	81°02'00"	1 Wilson-Lamison, Z	1.08	1.62	18,000
				1 Wilson-Lamison, N	5.15	4.00	7,000
				1 Wilson-Lamison, E	5.2	3.8	7,000
Dallas, Texas	DAL	32°50'46"	96°47'02"	3 Benioff 100 kg, N, E, Z	1.0	0.75	25,000
				3 Sprengnether, N, E, Z	30	100	1,500
Dubuque, Iowa	DBQ	42°30'24"	90°41'00"	1 Benioff 14 kg, Z	1.0	1.0	10,432
				1 Wood-Anderson	0.8	-	-
				3 Sprengnether, N, E, Z	15	90	-
Dugway, Utah	DUG	40°11'42"	112°48'48"	3 Benioff 100 kg, N, E, Z	1.0	0.75	400,000
				3 Sprengnether, N, E, Z	30	100	3,000
East Machias, Maine	EMM	44°44'21"	67°29'22"	3 Benioff 100 kg, N, E, Z	1.0	0.8	-
El Paso, Texas	EPT	31°46'18"	106°30'21"	1 Benioff 100 kg, Z	1.0	-	52,800
				2 Benioff 100 kg, N, E	1.0	-	40,000
Eureka, Nevada	EUR	39°29'00"	115°58'12"	1 Benioff M.C., Z	1.02	0.55	262,000
				1 Wilson-Lamison, Z	1.1	1.5	25,000
Fayetteville, Arkansas	FAY	36°05'28"	94°11'28"	1 Benioff 100 lb., M.C., Z	1.1	0.2	22,000
				1 Wilson-Lamison, N	6.0	4.1	-
				1 Wilson-Lamison, E	6.0	3.8	-
Flaming Gorge, Utah	FGU	40°55'35"	109°23'10"	1 Benioff M.C., Z	1.04	0.35	63,000
				1 Benioff M.C., N	1.38	0.37	
				1 Benioff M.C., E	1.42	0.32	
				1 Wilson-Lamison, N	0.78		-
				1 Wilson-Lamison, E	0.80		-

Florissant, Missouri	FLO	38°48'06"	90°22'12"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	50,000 1,500
Fordham, New York	FOR	40°51'5[illegible]"	73°53'08"	3 Willmore, N, E, Z 3 Press-Ewing, N, E, Z	1.0 15	0.25 90	3,000 3,000
Fresno, California	FRE	36°46'00"	119°47'48"	1 Sprengnether, Z 2 Sprengnether, N, E	2.0 2.0	2.0 2.0	10,900 6,500
Fort Tejon, California	FTC	34°52'24"	118°53'36"	1 Benioff, Z	1.0	0.2	-
Glen Canyon, Arizona	GCA	36°58'25"	111°35'35"	1 Benioff M.C., Z 1 Benioff M.C., N 1 Benioff M.C., E	1.06 1.41 1.38	0.37 0.43 0.44	52,000
Glen Cove, New York	GCY	40°51'30"	73°37'48"	Home Made, Z	3.4	17.6	1,300
Georgetown, Washington, D.C.	GEO	38°54'00"	77°04'00"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	25,000 1,500
Golden, Colorado	GOL	39°42'01"	105°22'16"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	200,000 1,500
Goldstone, California	GSC	35°18'06"	116°48'16.6"	3 Benioff 100 kg, N, E, Z 3 Press-Ewing, N, E, Z	1.0 30	0.75 100	200,000 1,500
Haiwee, California	HAI	36°08'12"	117°56'48"	1 Benioff, Z 2 Wood-Anderson, N, E	1.0 0.8	0.2 -	- 2,800
Hayfield, California	HAY	33°42'24"	115°38'12"	1 Benioff, N	-	-	-
Houston, Texas	HET	29°43'12"	95°28'11"	1 Electro-Tech, Z	5.0	25.0	10,000
Hungry Horse, Montana	HHM	48°20'58"	114°01'39"	1 Benioff M.C., Z 2 Sprengnether, N, E	1.0 3.4	0.5 3.9	- -
Isabella, California	ISA	35°38'36"	118°28'36"	1 Benioff, Z	1.0	0.[illegible]	-
Jamestown, California	JAS	37°56'4[illegible]"	120°26'18"	3 Benioff 100 kg, N, E, Z	1.0	0.75	255,000

Junction City, Texas	JCT	30°28'45"	99°48'08"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	100,000 3,000
Klamatn Falls, Oregon	KPO	42°16'00"	121°44'42"	1 Benioff 14 kg, Z	1.0	0.2	7,500
King Ranch, California	KRC	35°19'36"	119°44'42"	1 Benioff, Z	1.0	0.2	-
Laramie, Wyoming	LAR	41°18'52"	105°34'59"	1 Benioff, Z 1 Benioff, N 1 Benioff, E	1.0 1.0 1.0	0.8 1.0 0.6	96,000 34,400 44,000
Lawrence, Kansas	LAW	38°57'34"	95°1[illegible]0"	3 Sprengnether, N, E, Z	-	-	-
Llandad, California	LLA	36°37'00"	120°56'36"	1 Benioff 14 kg, Z	1.0	0.2	46,600
Longmire, Washington	LON	46°45'00"	121°48'36"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	100,000 1,500
Little Rock, Arkansas	LRA	34°47'00"	92°21'00"	1 Wilson-Lamison, Z 1 Sprengnether, Z	1.0 20	1.0 20	25,000 -
Lubbock, Texas	LUB	33°35'00"	101°52'00"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	25,000 1,500
Madison, Wisconsin	MDS	43°22'20"	89°45'36"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	100,000 1,500
Mt. Hamilton, California	MHC	37°20'30"	121°38'30"	1 Benioff 100 kg, Z 2 Wood-Anderson, N, E	1.0 0.8	0.4	- 2,800
Mammoth Hot Springs, Wyoming	MHS	44°58'48"	110°41'42"	1 Sprengnether, Z	1.09	-	-
Manhattan, Kansas	MHT	39°11'59"	96°34'50"	1 Benioff 14 kg, Z 1 Benioff 14 kg, N 1 Benioff 14 kg, E 3 Sprengnether, N, E, Z	1.0 1.0 1.0 15	1.0 1.0 1.0 90	25,000 30,000 22,000 -
Mile, Maine	MIM	45°14'37"	69°02'25"	3 Benioff 100 kg, N, E, Z	1.0	0.8	-

Mineral, California	MIN	40°20'42"	121°36'18"	1 Benioff 100 kg, Z	1.0	0.4	75,000
				2 Wood-Anderson, N, E	0.8		2,800
Milford, Ohio	MLF	39°08'14.6"	8[illegible]°16'38.8"	1 Benioff 14 kg, Z	1.05	0.76	50,000
				1 Benioff 14 kg, N	0.95	0.[illegible]	45,000
				1 Benioff 14 kg, E	0.92	0.73	45,000
Minneapolis, Minnesota	MNN	44°54'52"	93°11'24"	3 Benioff 100 kg, N, E, Z	1.0	0.75	50,000
				3 Sprengnether, N, E, Z	30	100	3,000
Morgantown, West Virginia	MRG	39°37'59"	79°57'16"	3 Sprengnether, N, E, Z	1.5	-	5,000
Mt. Wilson, California	MWC	34°13'24"	118°03'30"	1 Benioff, Z	1.0	0.2	-
New Orleans, Louisiana	NOL	29°56'54"	90°07'12"	1 Sprengnether S.P., Z	-	-	-
				2 Sprengnether L.P., N, E	-	-	-
Ogdensburg, New Jersey	OGD	41°04'00"	74°37'00"	3 Benioff 100 kg, N, E, Z	1.0	0.75	100,000
				3 Sprengnether, N, E, Z	30	100	750
				3 Willmore, N, E, Z	1.0	15.0	-
				3 Hall-Sears, N, E, Z	2.0	90.0	-
Oroville, California	ORV	39°33'20"	121°30'00"	3 Benioff 100 kg, N, E, Z	1.0	0.75	100,000
				3 Sprengnether, N, E, Z	30	100	3,000
Oxford, Mississippi	OXF	34°30'42"	89°24'33"	3 Benioff 100 kg, N, E, Z	1.0	0.75	50,000
				3 Sprengnether, N, E, Z	30	100	1,500
Palo Alto, California	PAC	37°25'00"	122°10'54"	1 Benioff 100 kg, Z	1.0	0.4	15,000
				2 Wood-Anderson, N, E	0.8	-	2,800
Palisades, New York	PAC	41°00'25"	73°54'31"	3 Columbia U., N, E, Z	12	15	-
				3 Benioff, N, E, Z	1.0	0.2	-
				3 Benioff, N, E, Z	1.0	75	-
				1 Columbia U., Z	0.33	0.2	-
				3 Columbia U., N, E, Z	15	75	-
				3 Columbia U., N, E, Z	30	100	-
Pasadena, California	PAS	34°08'54"	118°10'18"	3 Benioff, N, E, Z	1.0	0.2	60,000
				3 Benioff, N, E, Z	1.0	90	10,000
				3 Press-Ewing, N, E, Z	30	90	2,000

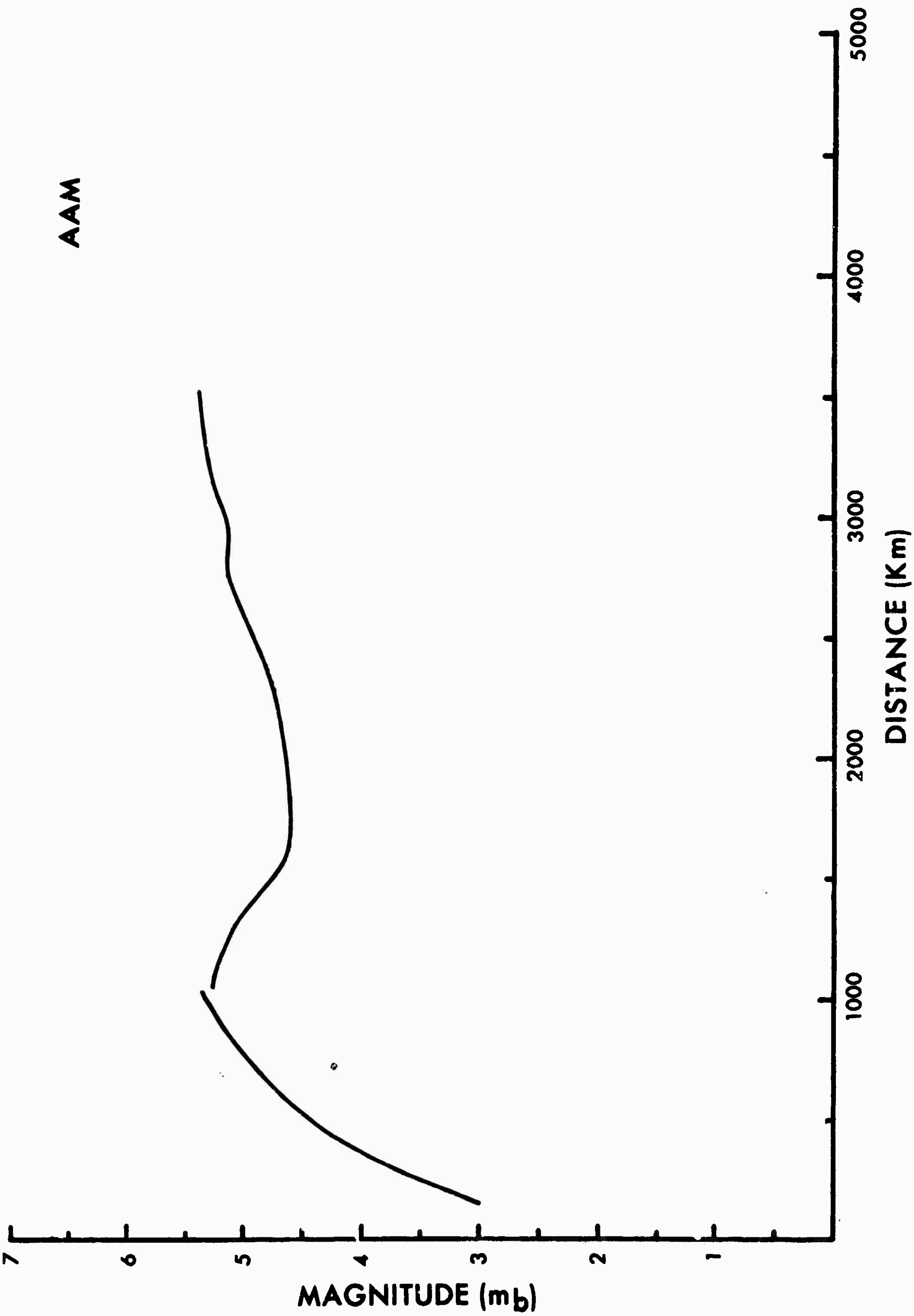
Price, Utah	PCU	39°35'24"	110°48'18"	1 Benioff 100 kg, Z 1 Benioff 100 kg, N 1 Benioff 100 kg, E	1.0 1.0 1.0	0.75 0.75 0.75	24,370 10,860 10,450
Philadelphia, Pennsylvania	PHI	39°57'32"	75°10'30"	1 Wenner 500 kg, N 1 Wenner 500 kg, E	9.0 8.7	5.6 9.2	-
Palomar, California	PLM	33°21'12.4"	116°51'42.1"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	50,000 750
Paraiso, California	PRS	36°19'54"	121°22'12"	1 Benioff 14 kg, Z	1.0	0.2	32,300
Rapid City, South Dakota	RCD	44°04'30"	103°12'30"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	12,500 750
Reno, Nevada	REN	39°32'24"	119°48'45"	1 Sprengnether, Z 1 Sprengnether, E	15 15	100 75	1,200 1,000
Rolla, Missouri	ROL	37°55'04"	91°52'08"	1 Benioff 14 kg, Z 1 Benioff 14 kg, N 1 Benioff 14 kg, E 3 Sprengnether, N, E, Z	1.0 1.0 1.0 15	1.0 1.0 1.0 90	35,000 21,000 14,000 -
Ruth, Nevada	RUT	39°14'00"	114°59'00"	3 Press-Ewing, N, E, Z	30	90	-
Riverside, California	RVR	33°59'36"	117°22'30"	3 Benioff, N, E, Z 3 Benioff, N, E, Z	1.0 1.0	0.2 90	150,000 10,000
Santa Cruz, California	SCC	37°00'24"	121°59'48"	1 Benioff 14 kg, Z	1.0	0.2	30,400
State College, Pennsylvania	SCP	40°48'35"	77°52'10"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	50,000 750
Seattle, Washington	SEA	47°39'18"	122°18'30"	3 Sprengnether, N, E, Z	1.4	1.4	1,400
San Francisco, California	SFB	37°46'36"	122°27'06"	1 Lehner-Griffith, Z 2 Wood-Anderson, N, E	1.2 0.8	0.3	12,000 2,800
Spring Hill, Alabama	SHA	30°41'41"	88°08'23"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	6,250 3,000

Salt Lake City Utah	SLC	40°45'55"	111°50'54"	1 Wilson-Lamison, Z 1 McComb-Romberg, N 1 McComb-Romberg, E	1.1 12.0 9.3	1.68 -	9,000 -
St. Louis, Missouri	SLM	38°38'10"	90°14'10"	1 Benioff, Z 1 Wood-Anderson 2 Sprengnether, Z, N	1.0 0.8 15	1.0 - 90	6,000 - -
San Nicolas, California	SNC	33°14'54"	119°31'24"	1 Benioff, Z 1 Benioff, Z 1 Wood-Anderson, E	1.0 1.0 0.8	0.2 90 -	- - -
Socorro, New Mexico	SNM	34°04'12"	106°56'36"	1 Willmore, Z 1 Press-Ewing, Z	1.1 10	- -	100,000 -
Spokane Washington	SPO	47°43'48"	117°20'32"	1 Benioff 100 kg, Z	1.0	0.75	46,000
Tinemaha, California	TIN	37°03'18"	118°13'42"	1 Benioff, Z 3 Benioff, N, E, Z 2 Wood-Anderson, N, E	1.0 1.0 0.8	0.2 90 -	- - 2,800
Tonopah, Nevada	TNP	38°04'55"	117°13'05"	1 Benioff 100 kg, Z 2 Benioff 100 kg, N, E	0.95 0.98	0.2 0.2	220,000 220,000
Tucson, Arizona	TUC	32°18'35"	110°46'56"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	200,000 3,000
Tulsa, Oklahoma	TUL	35°54'33"	95°47'33"	3 Benioff 100 kg, N, E, Z 3 Press-Ewing, N, E, Z	1.0 25	0.75 95	46,000 1,800
Tumwater, Washington	TUM	47°00'54"	122°54'30"	3 Sprengnether, N, E, Z	1.4	1.4	-
Ukiah, California	UKI	39°08'14"	123°12'38"	1 McComb-Romberg, N 1 McComb-Romberg, E 1 Wilson-Lamison, Z	11.9 11.5 1.65	- - 1.15	- - -
Unionville, Nevada	UVN	40°26'32"	118°09'30"	1 Johnson-Matheson, Z	1.27	0.08	130,000
Vineyard, California	VIN	36°45'00"	121°23'06"	2 Wood-Anderson, N, E	0.8	-	2,800
Vineyard, California	VIT	36°45'00"	121°23'18"	1 Benioff 14 kg, Z	1.0	0.2	24,000

Woody, California	WDY	35°42'00"	118°50'48"	1 Benioff, Z 1 Wood-Anderson, E	1.0 0.8	0.2	300,000 2,800
Weston, Massachusetts	WES	42°23'05"	71°19'20"	3 Benioff 100 kg, N, E, Z 3 Sprengnether, N, E, Z	1.0 30	0.75 100	50,000 1,500
Waterville, Maine	WTR	44°33'42"	69°39'36"	1 Wilson-Lamison, Z	0.5	1.5	25,000

*The instrumentation listed for each station is based on the latest available information as of April 1965.

APPENDIX II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6
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4
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2
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DISTANCE (Km)
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4000
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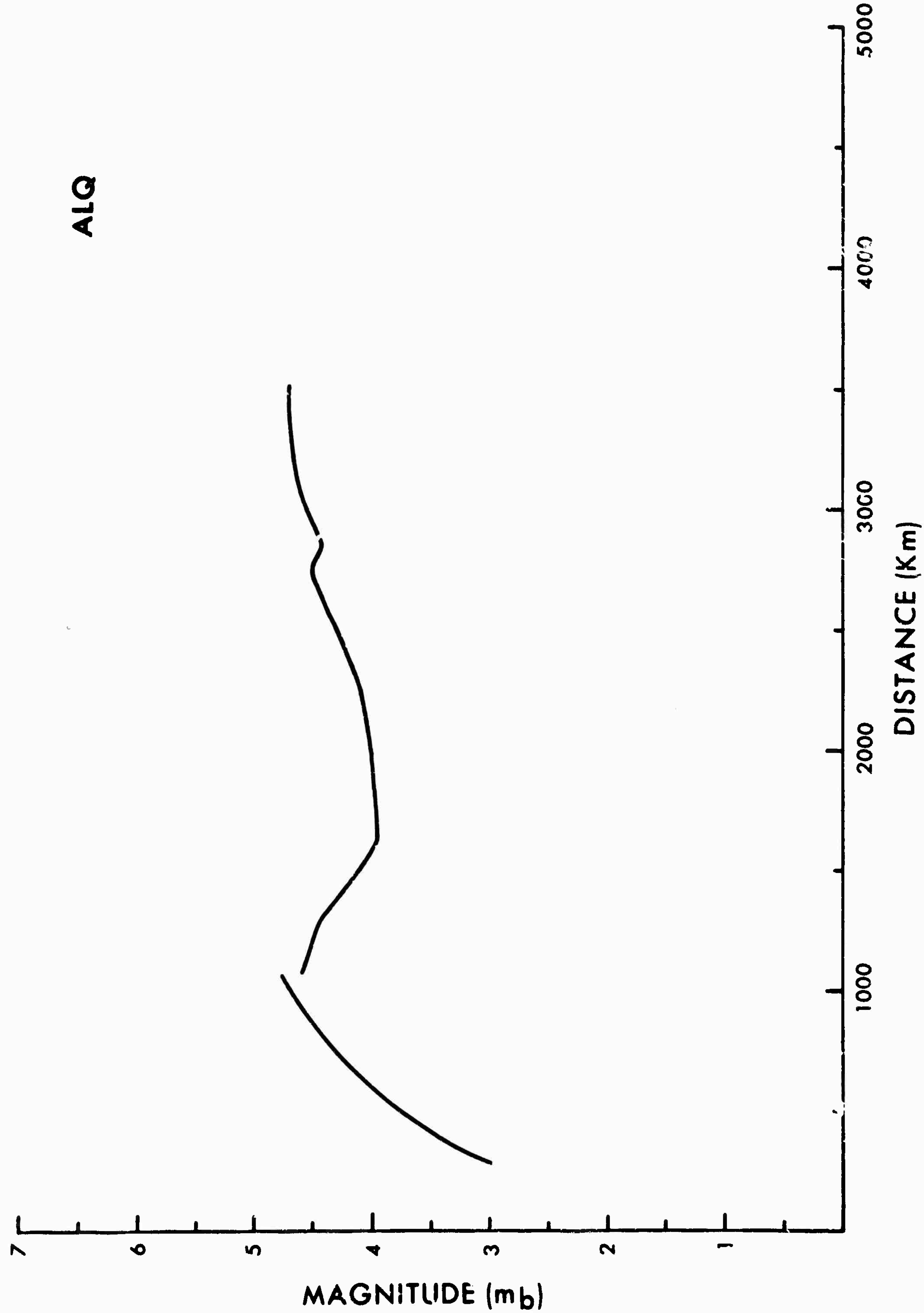
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DISTANCE (Km)
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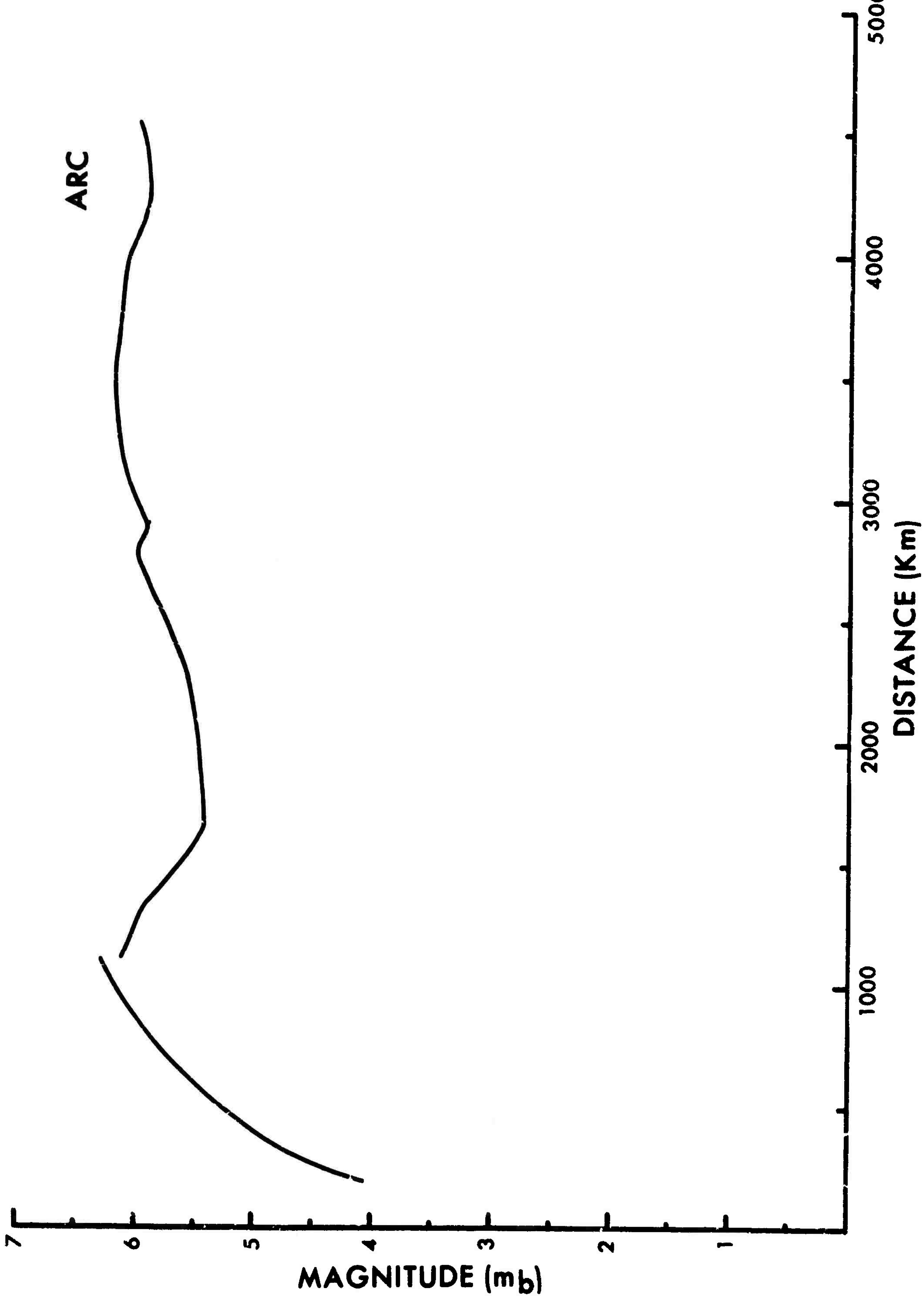
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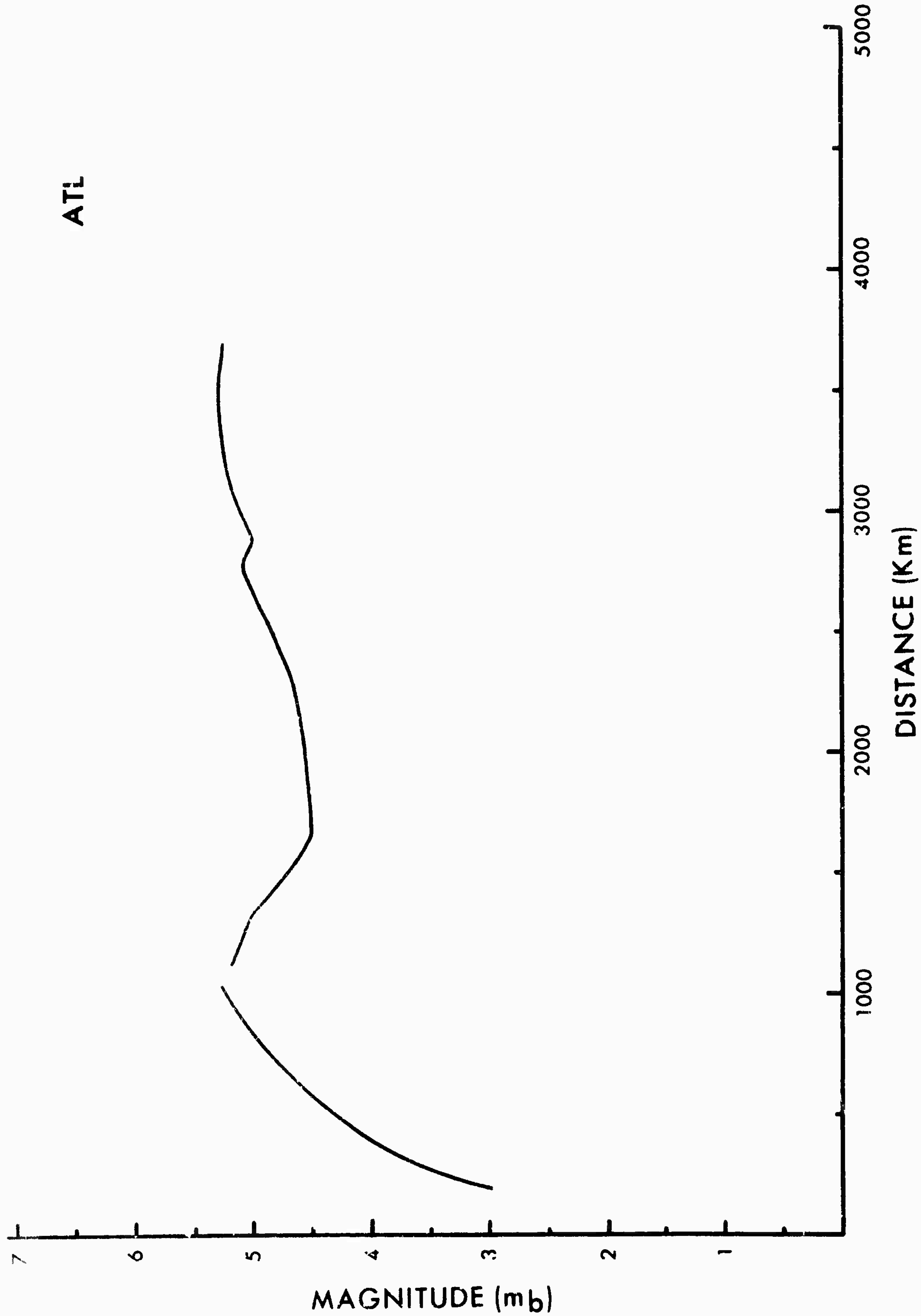
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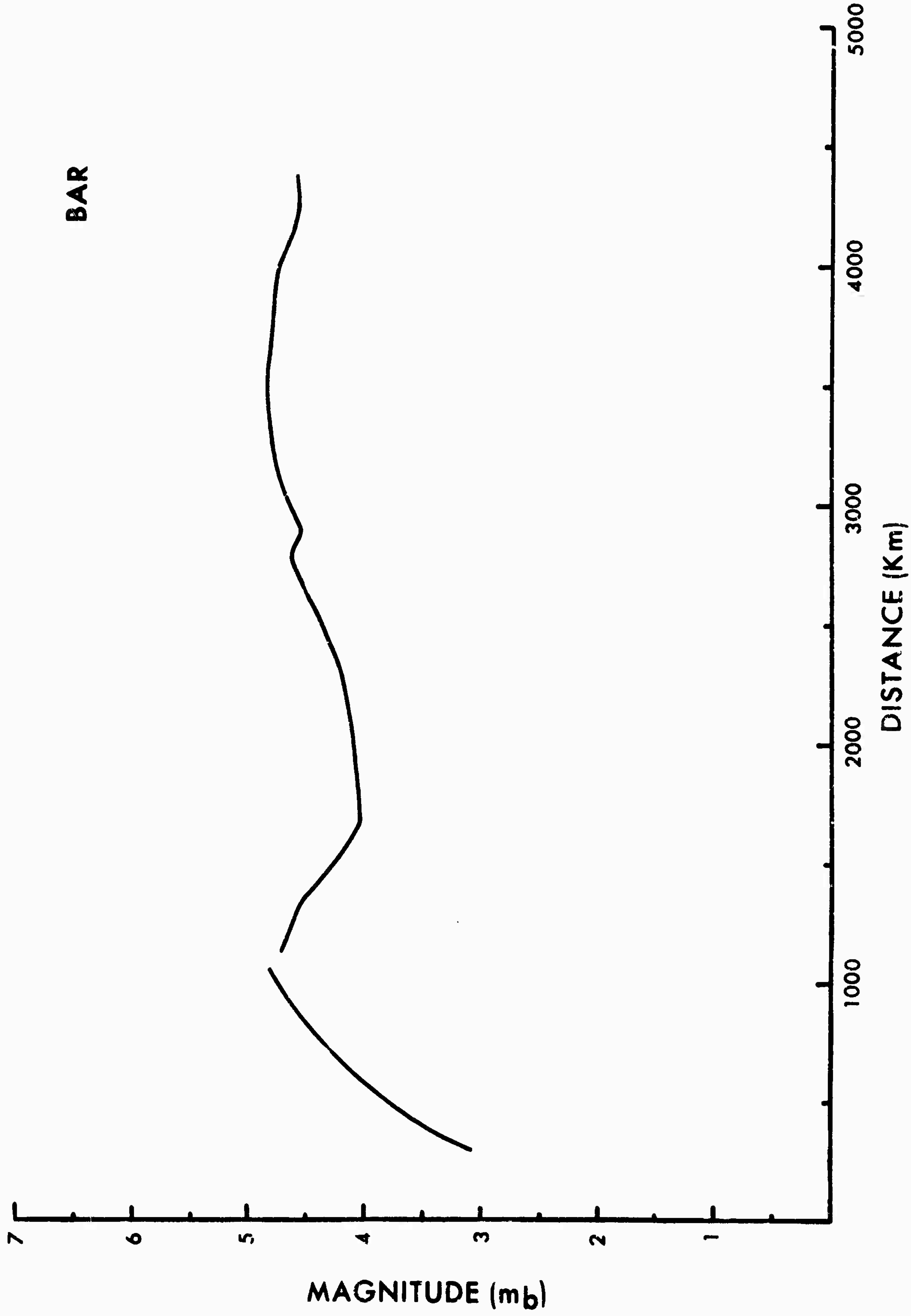
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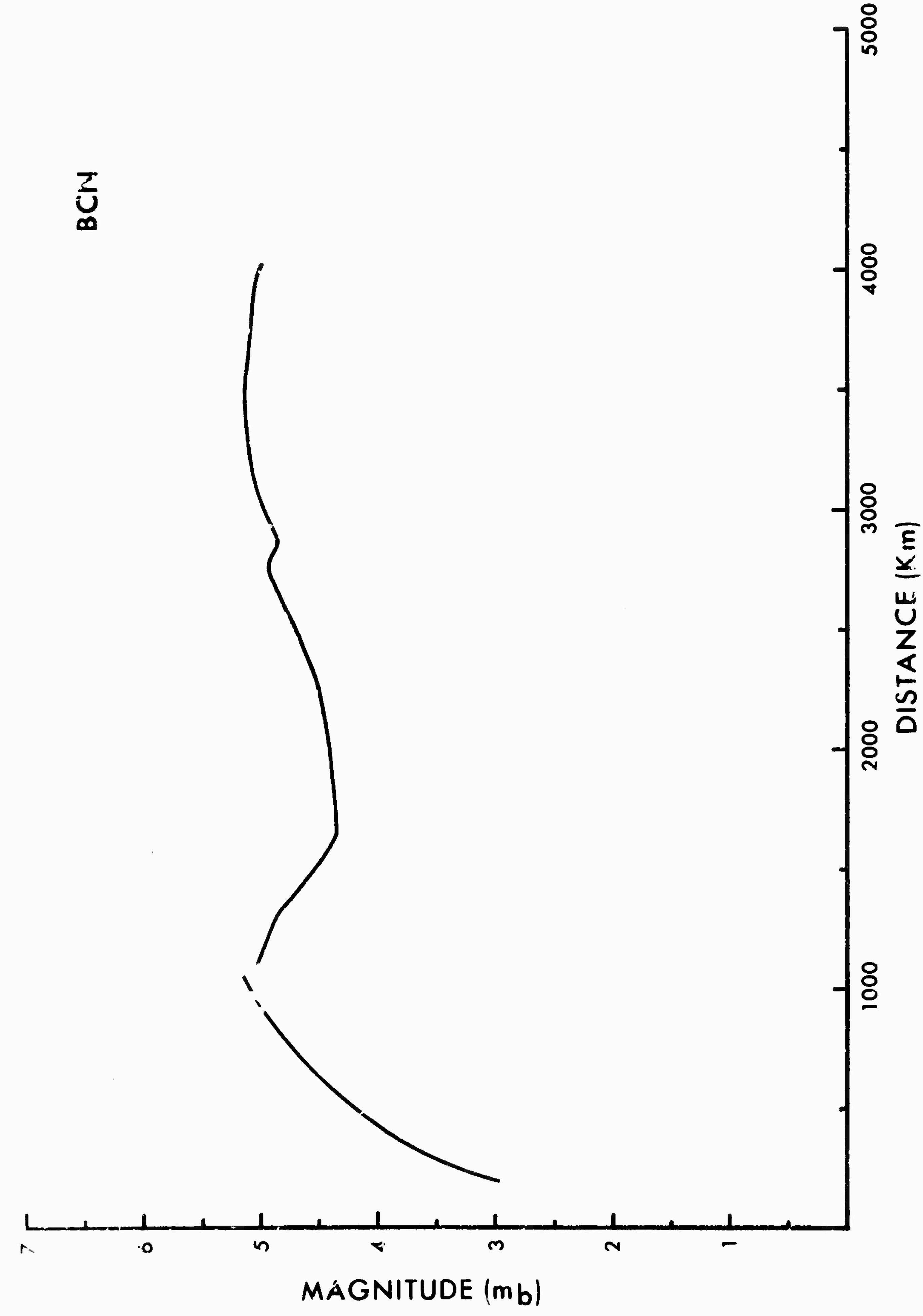
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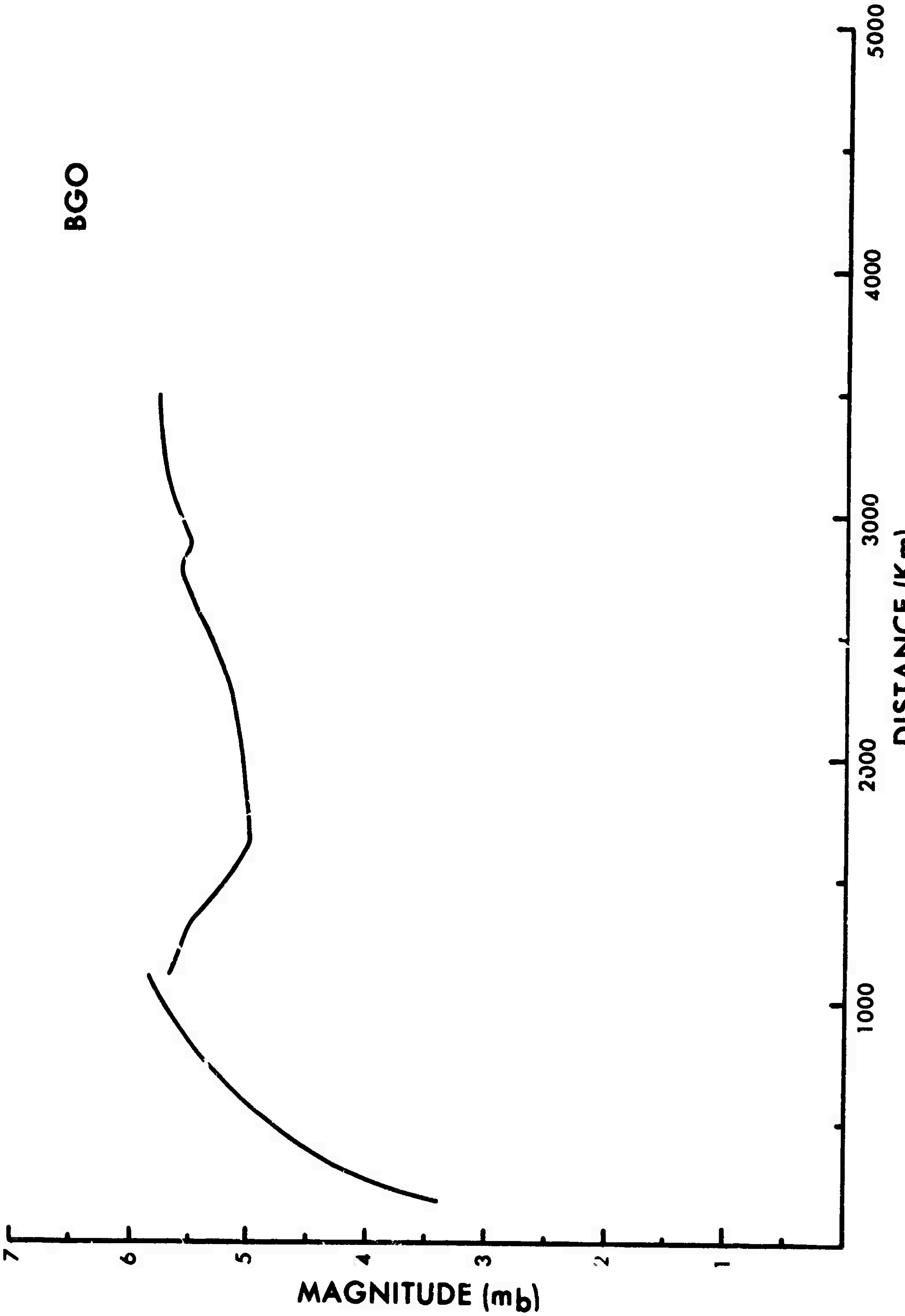
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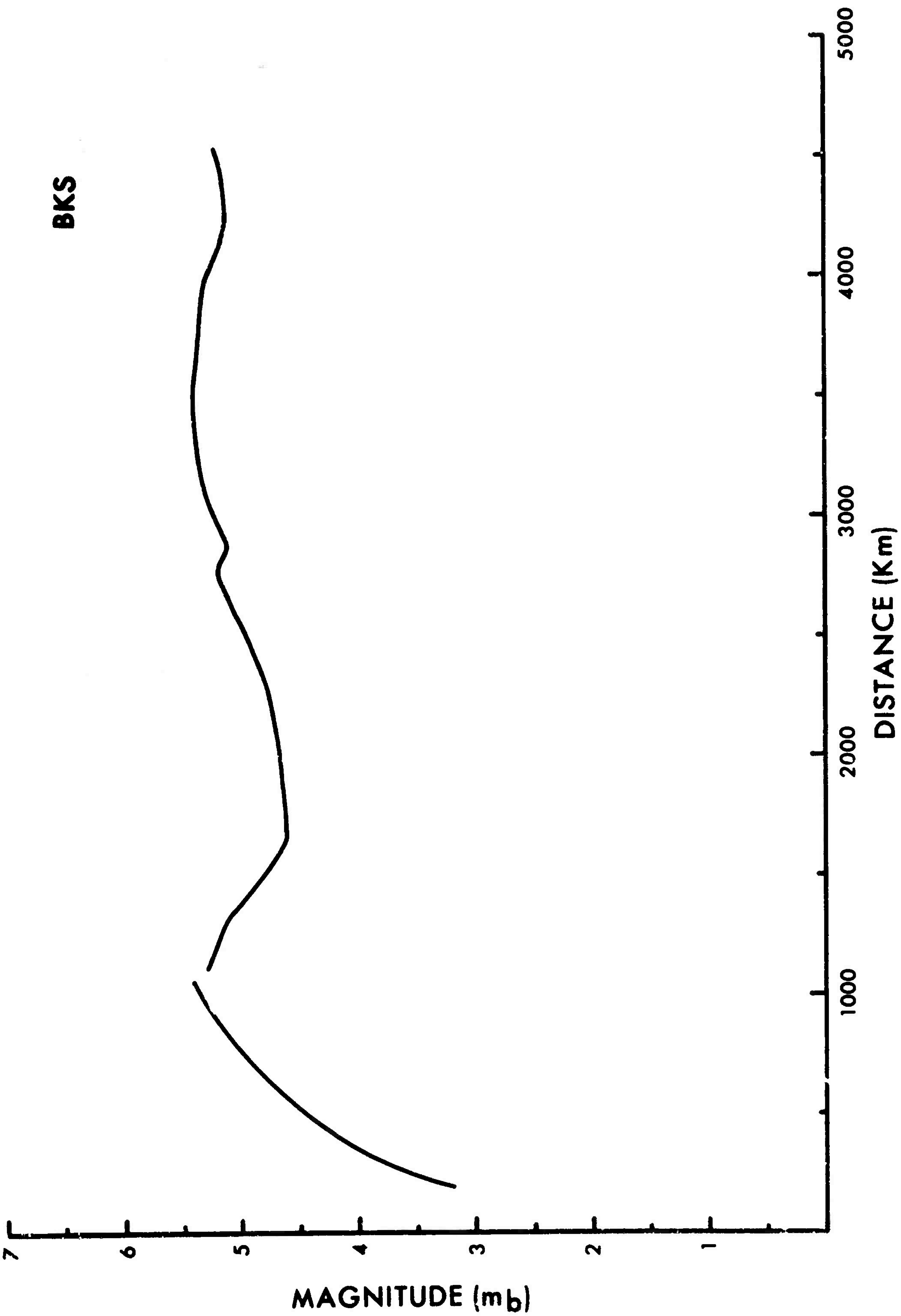
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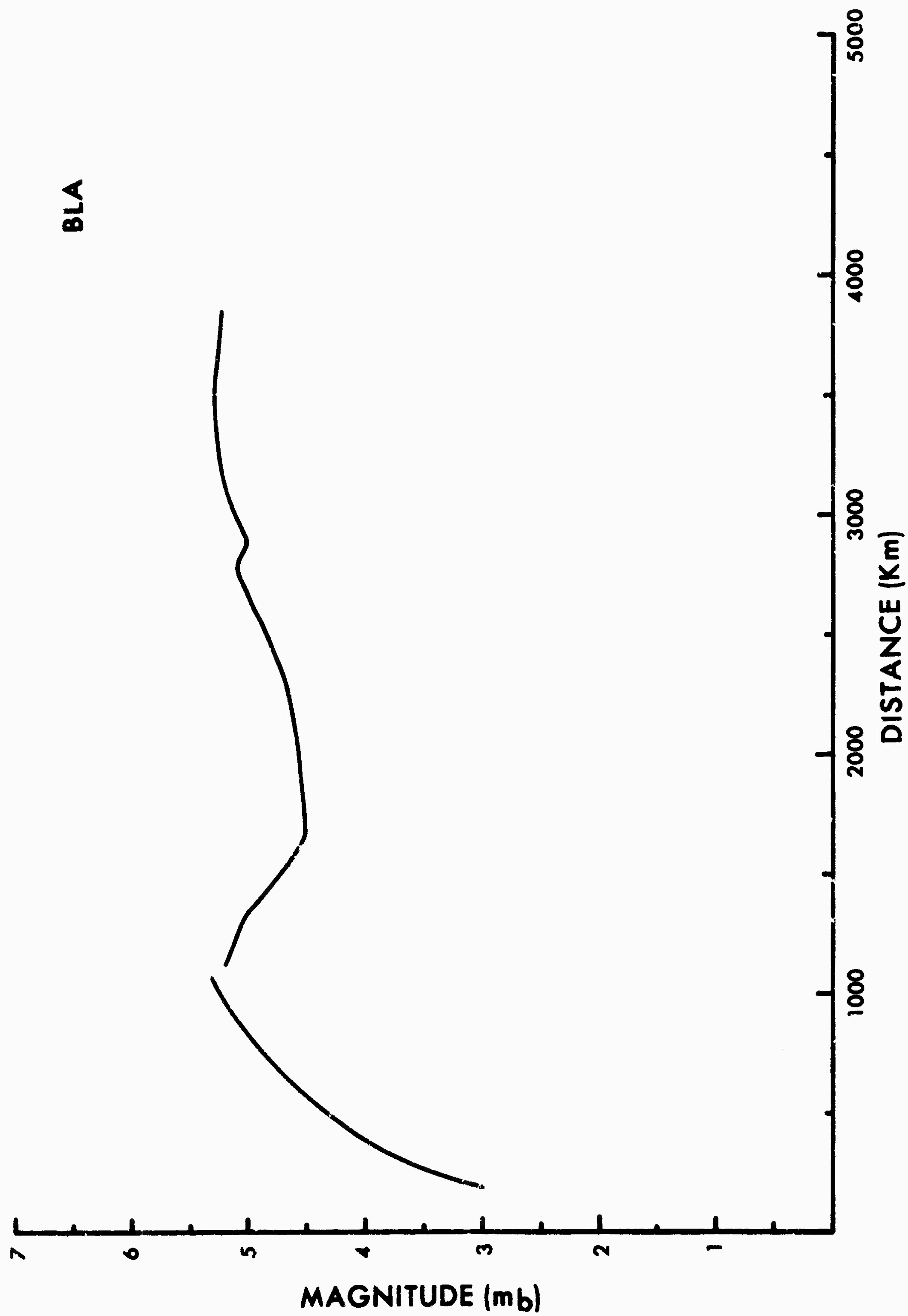
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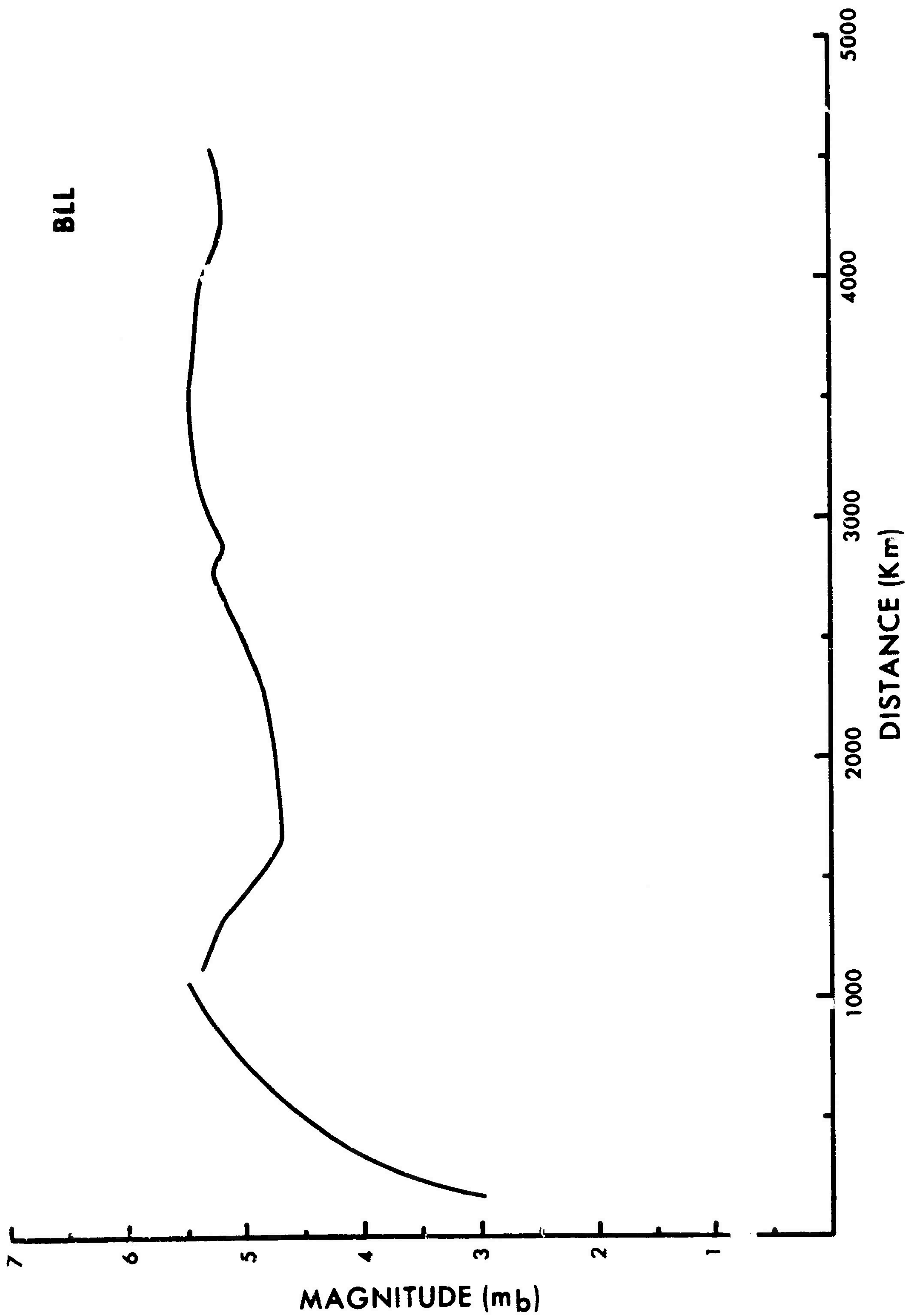
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DISTANCE (Km)
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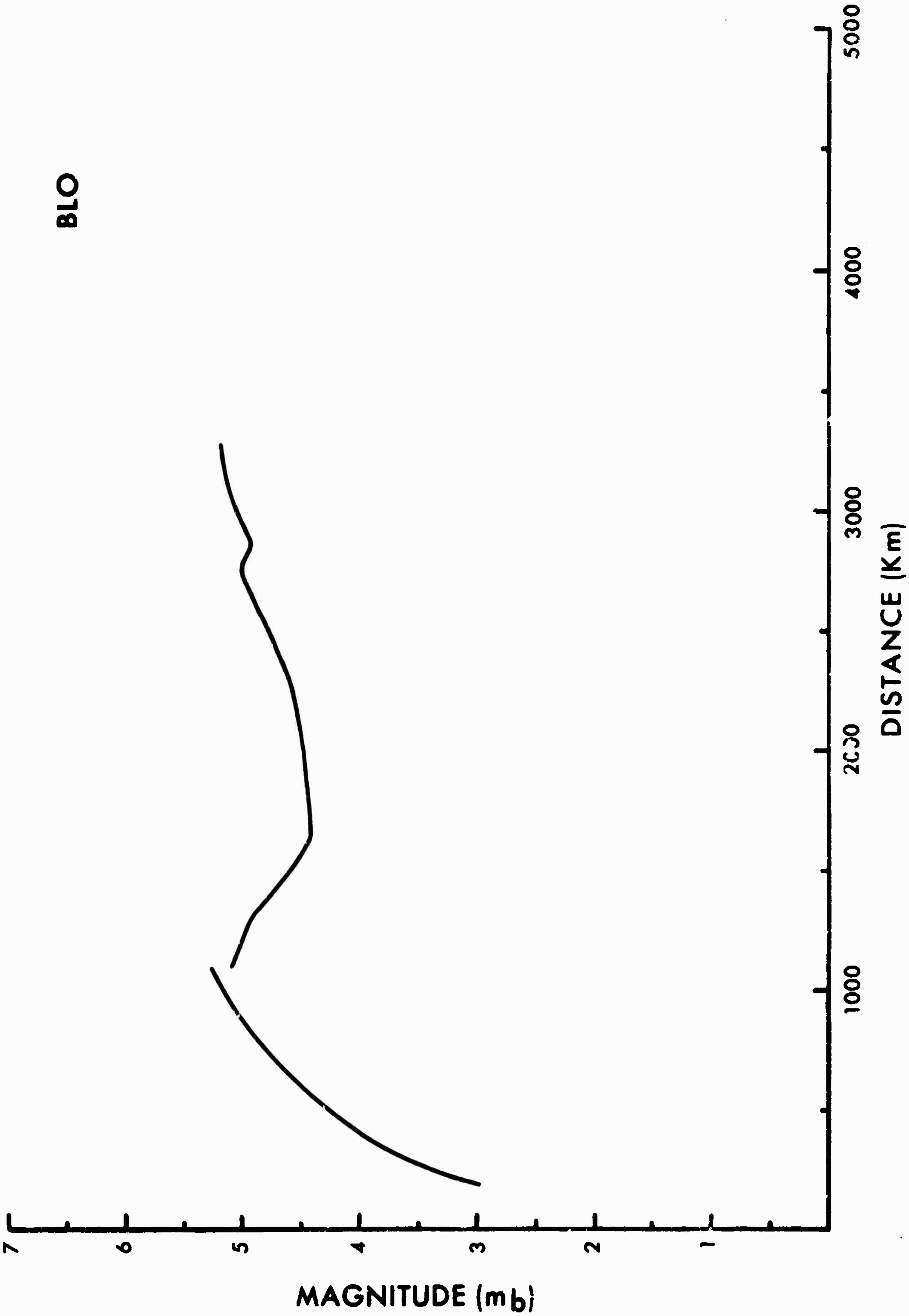
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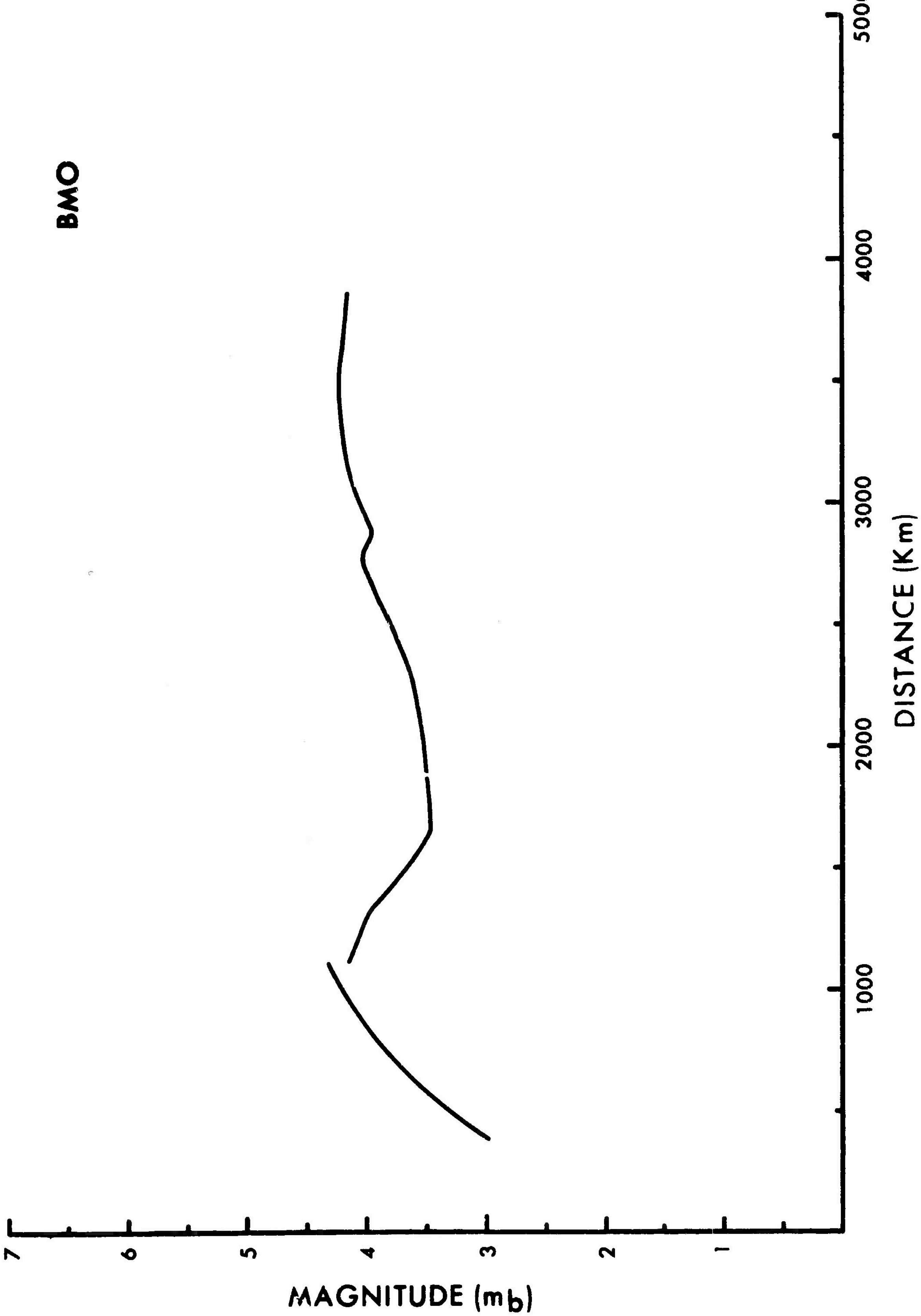
MAGNITUDE (mb)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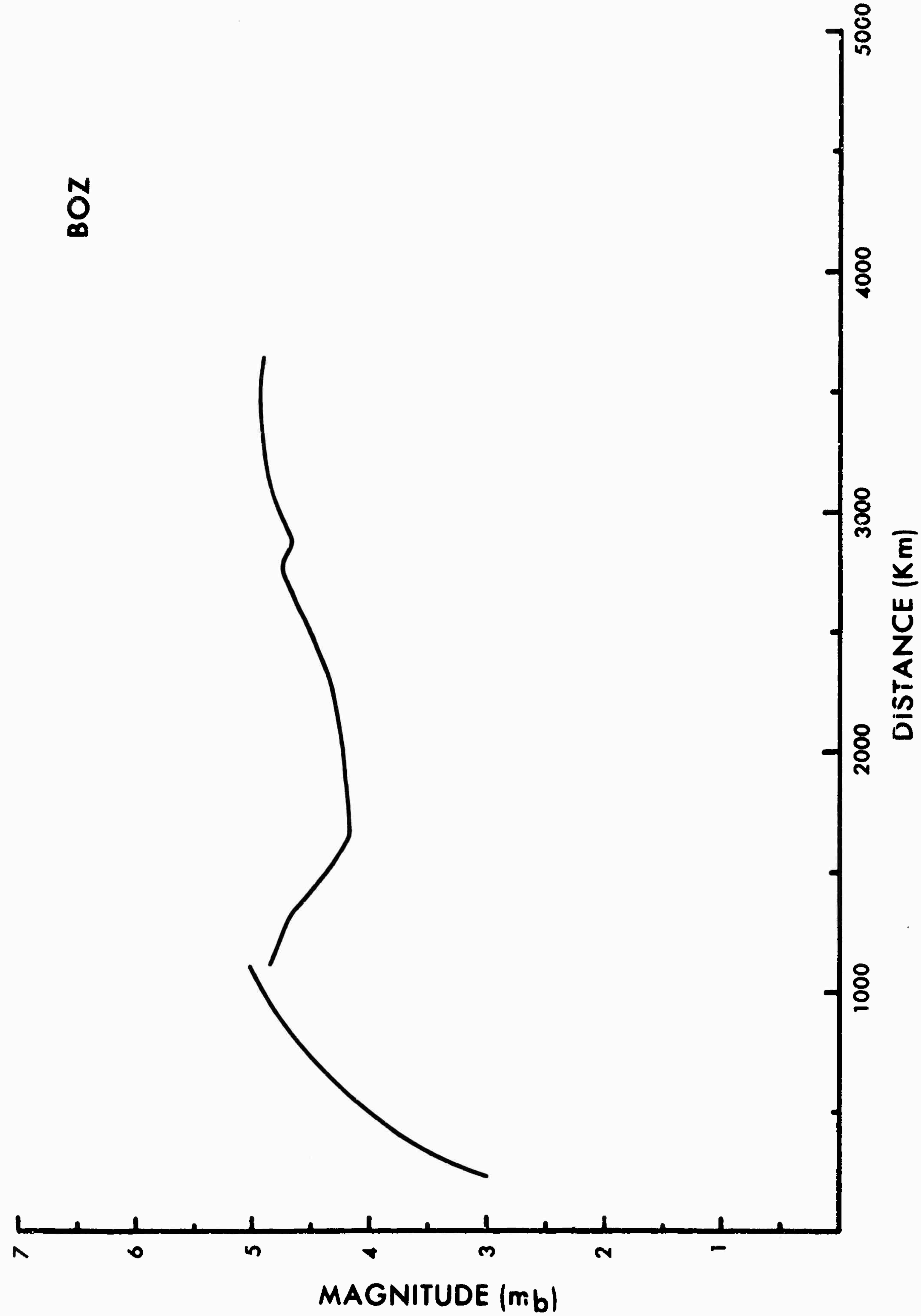
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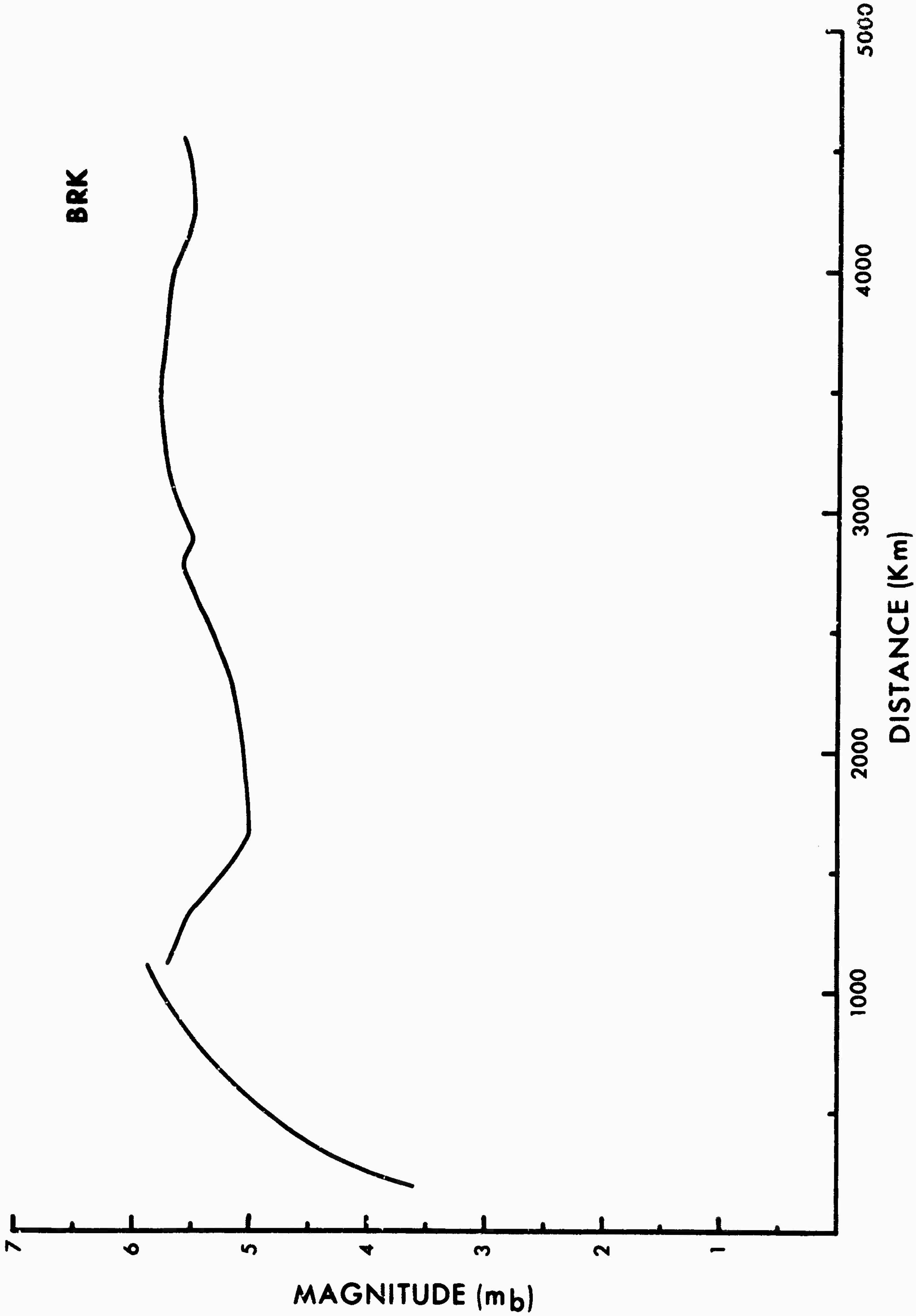
MAGNITUDE (mb)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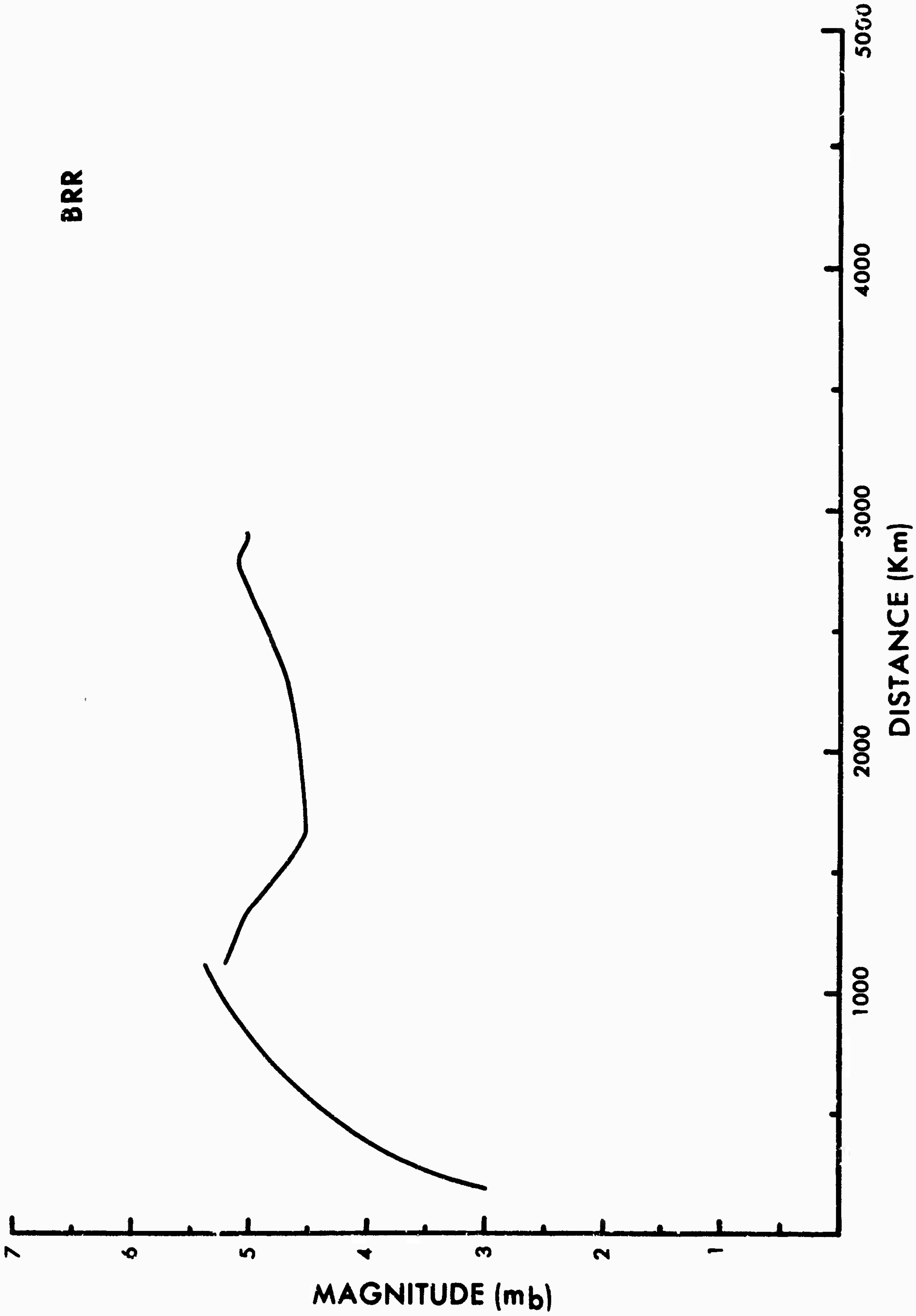
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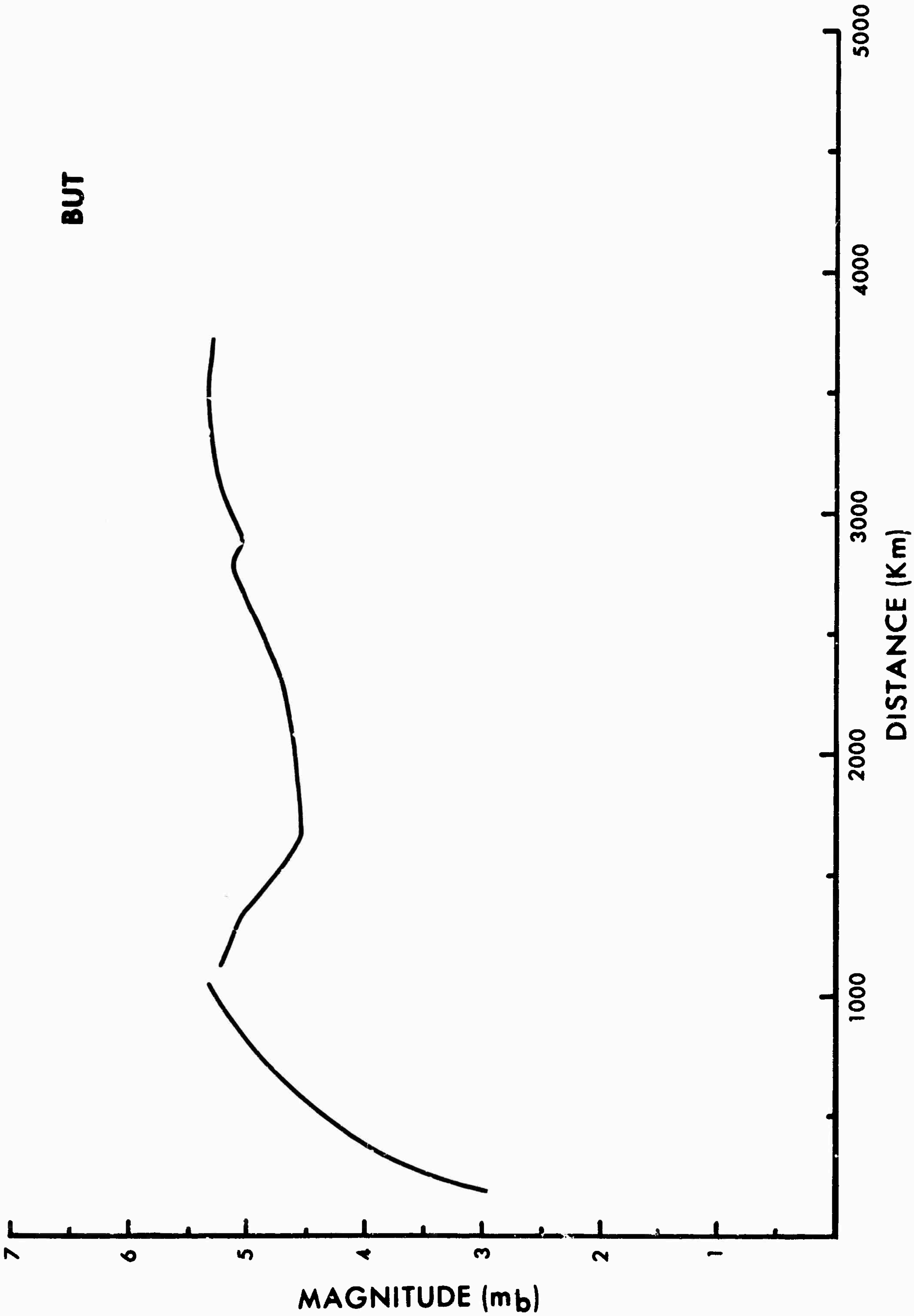

BUT
7
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MAGNITUDE (m_b)
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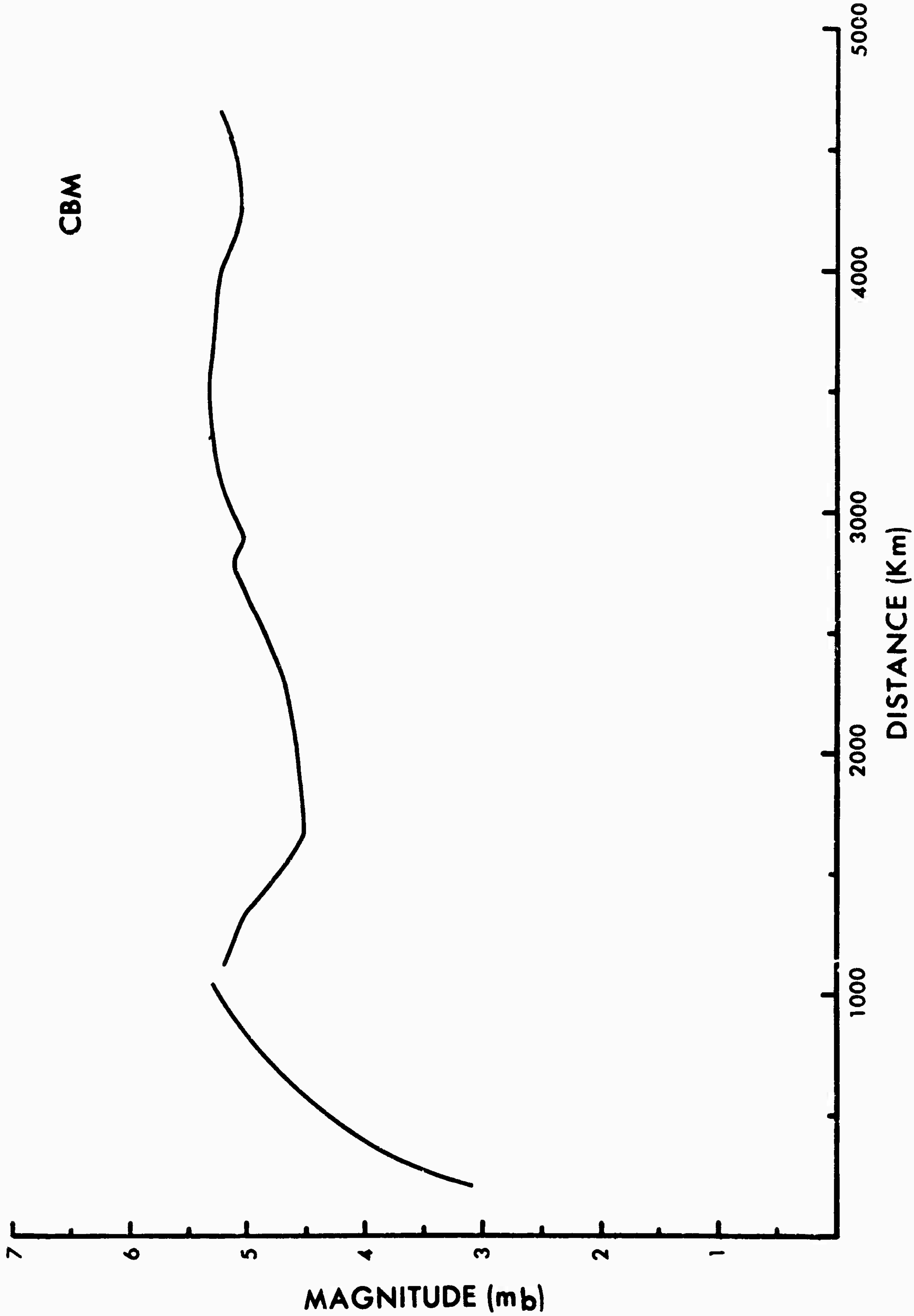
DISTANCE (Km)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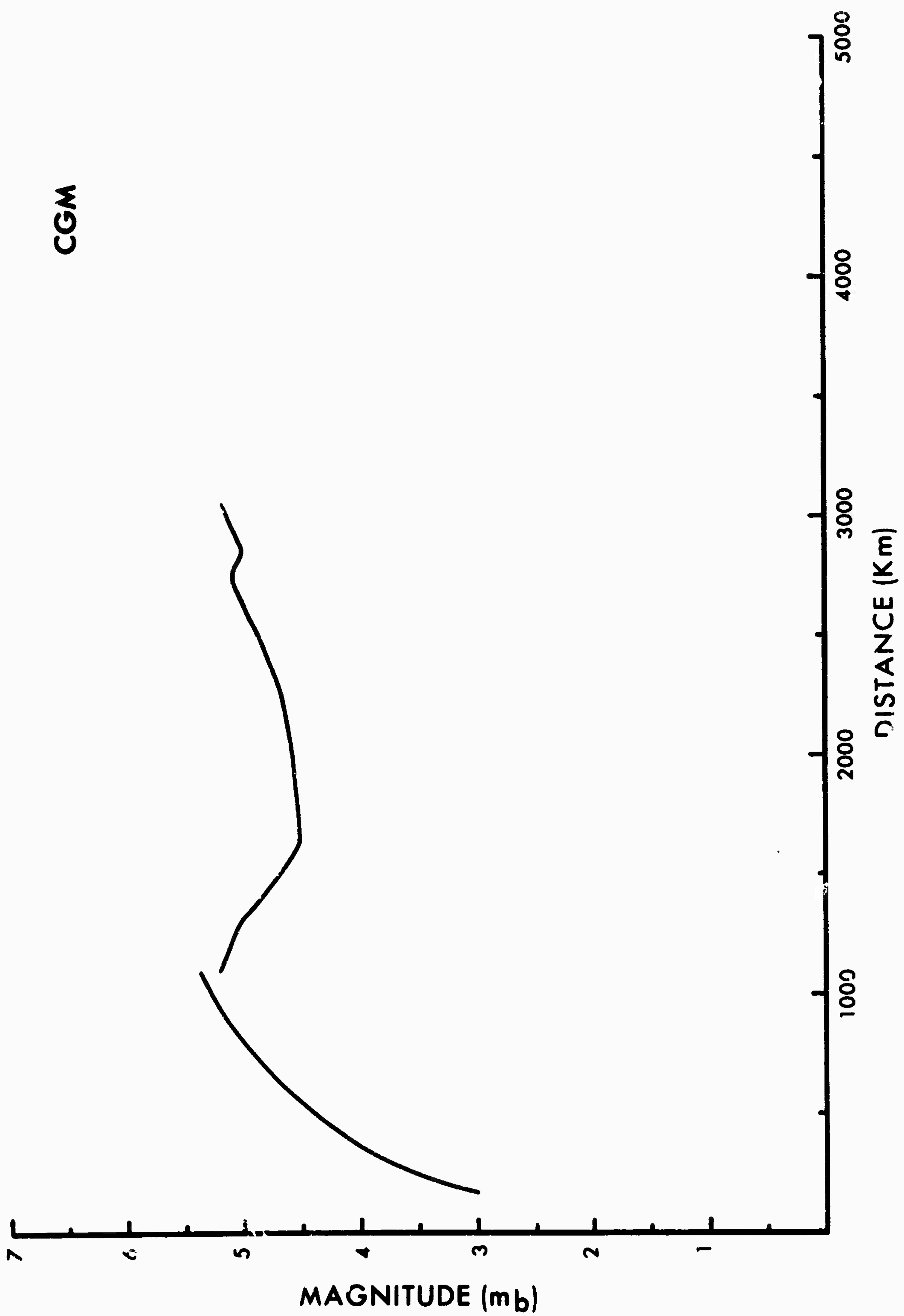
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MAGNITUDE (mb)
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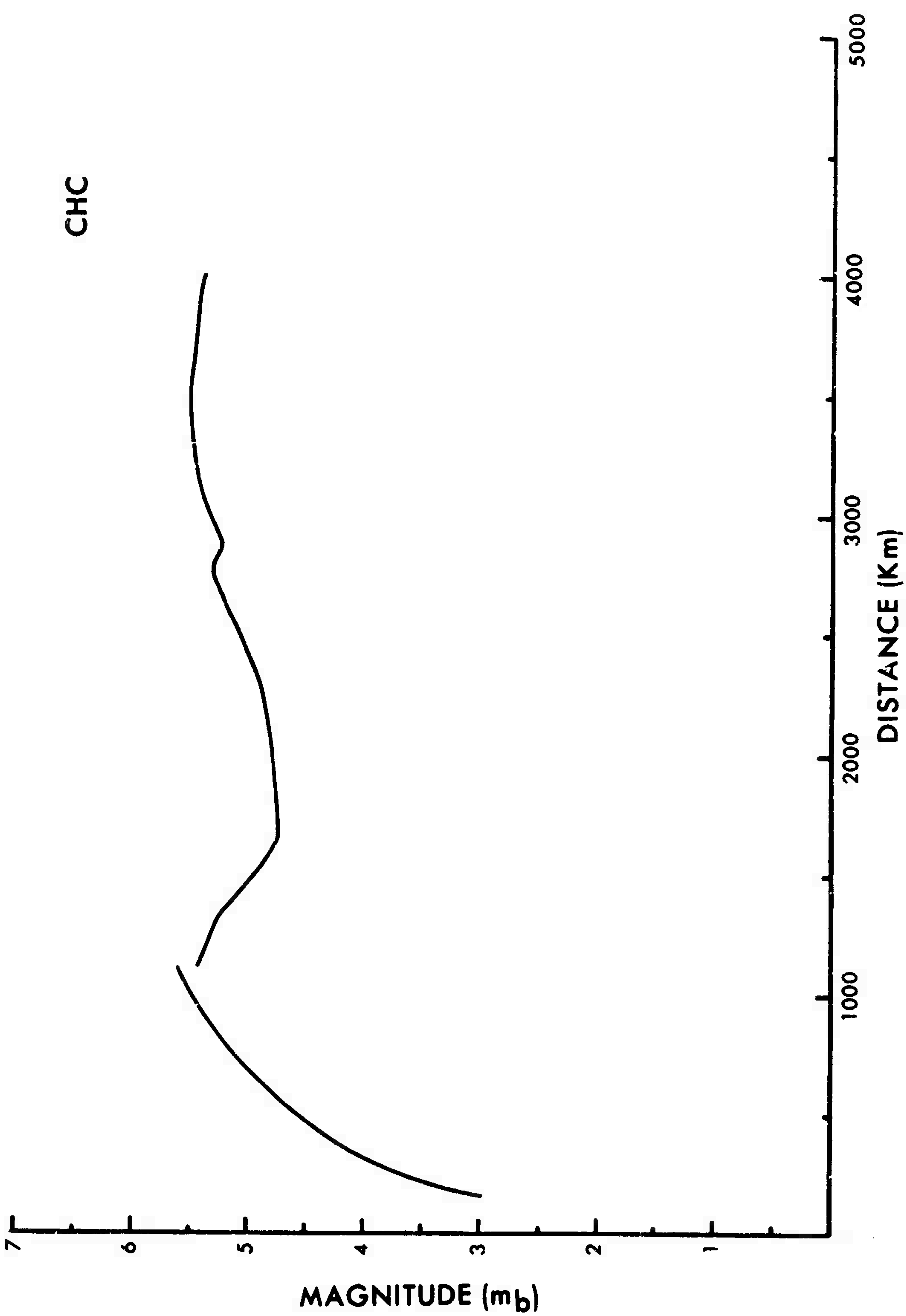
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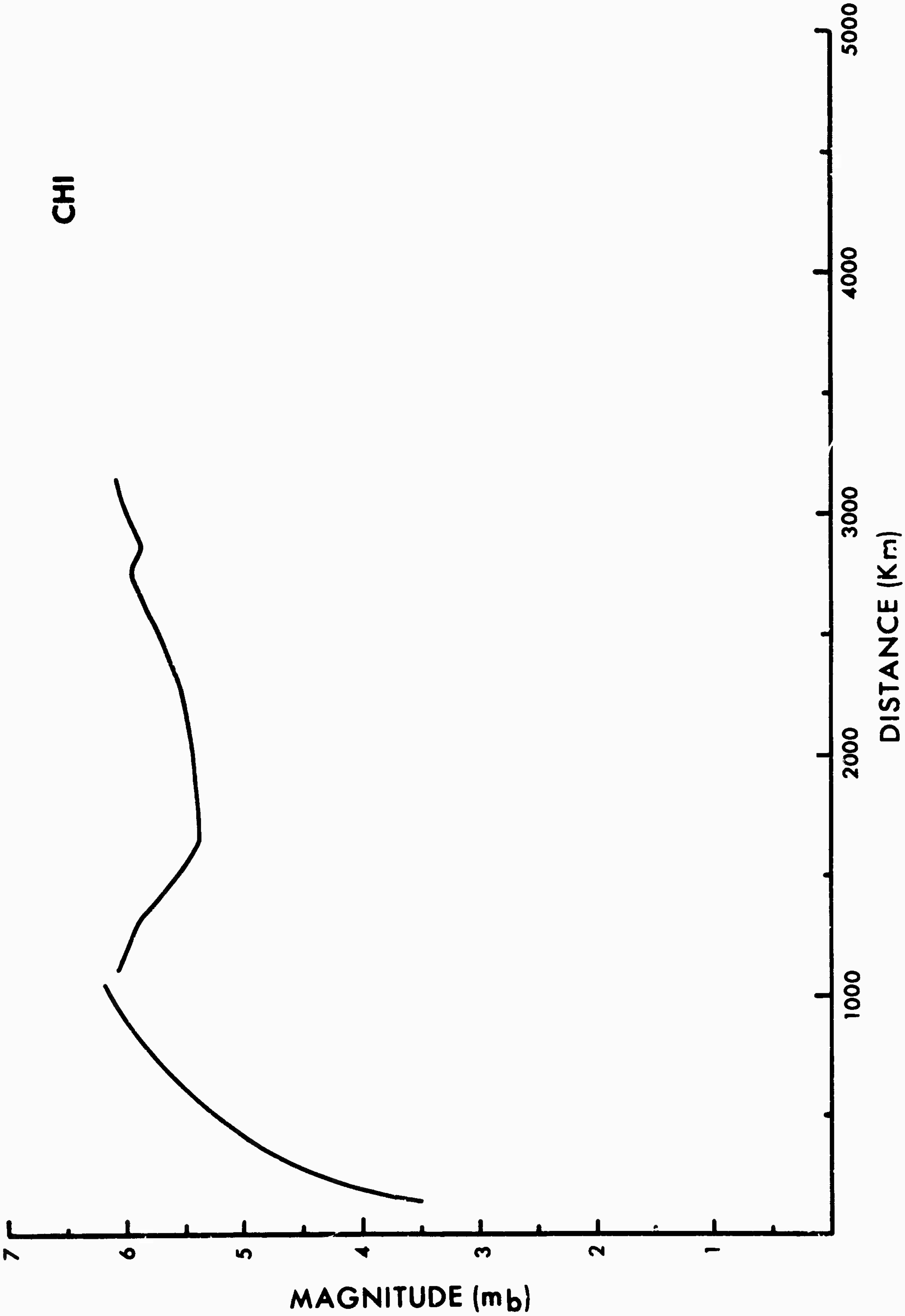
5000
DISTANCE (Km)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MAGNITUDE (m_b)
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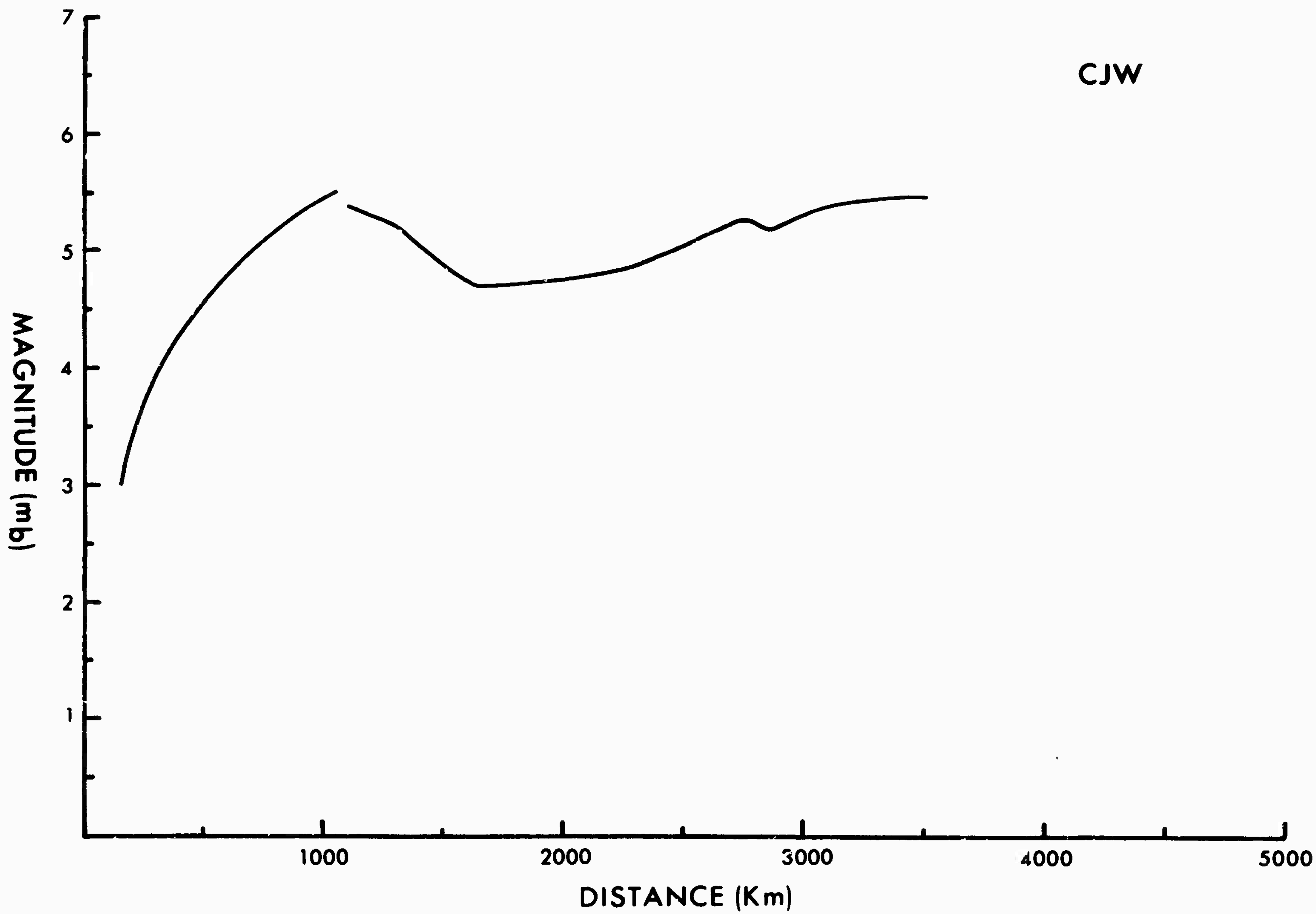
CJW
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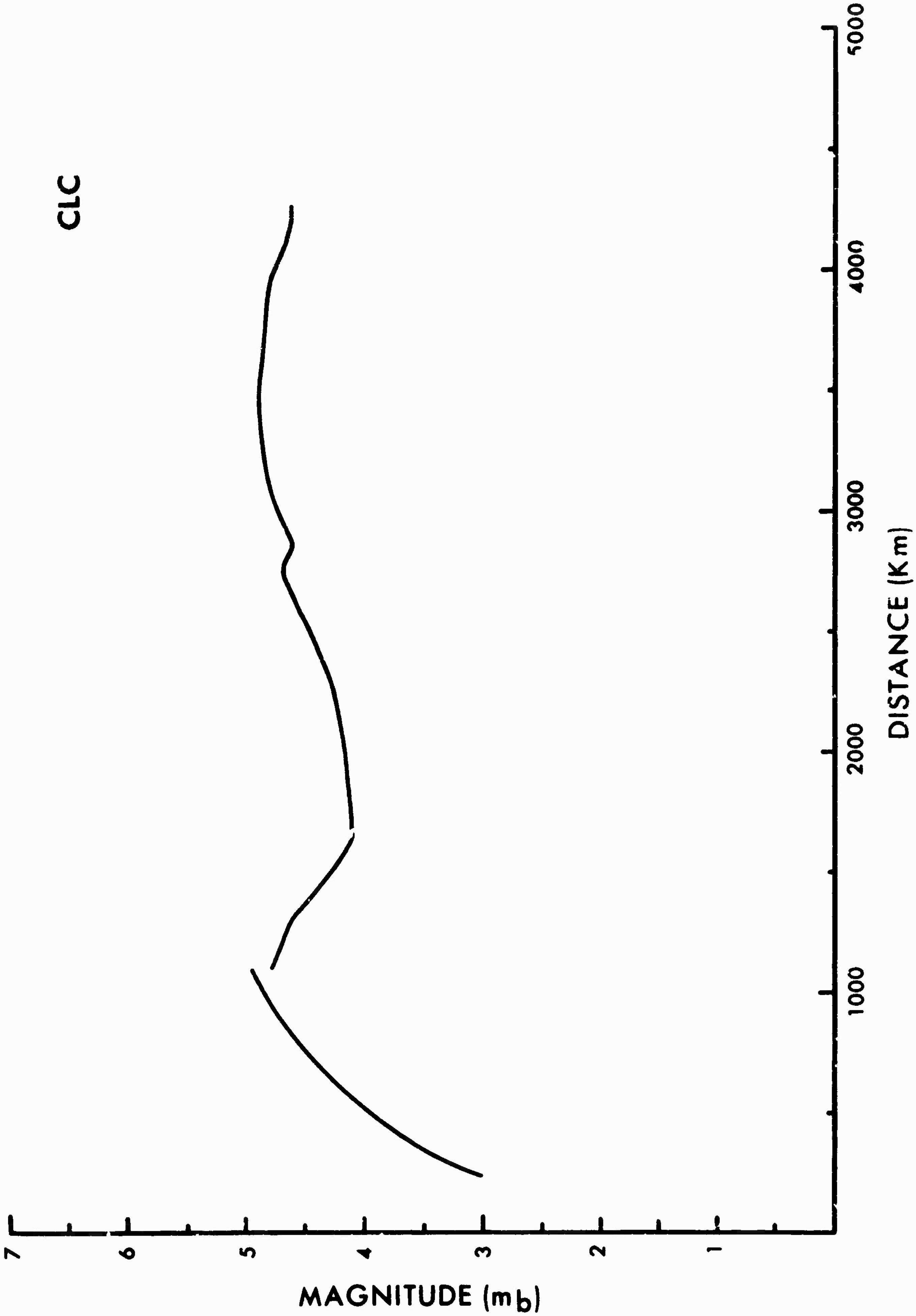
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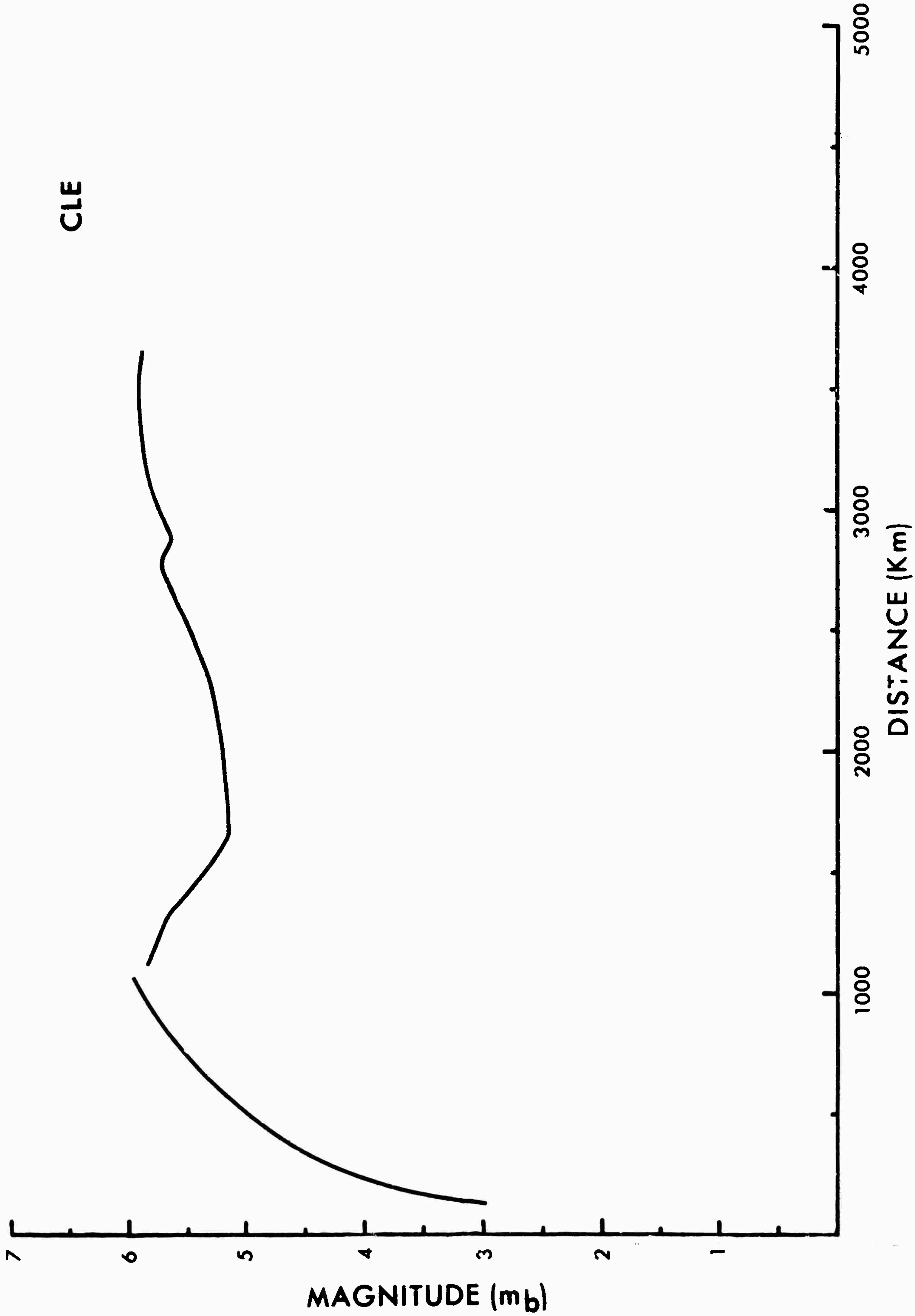
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DISTANCE (Km)
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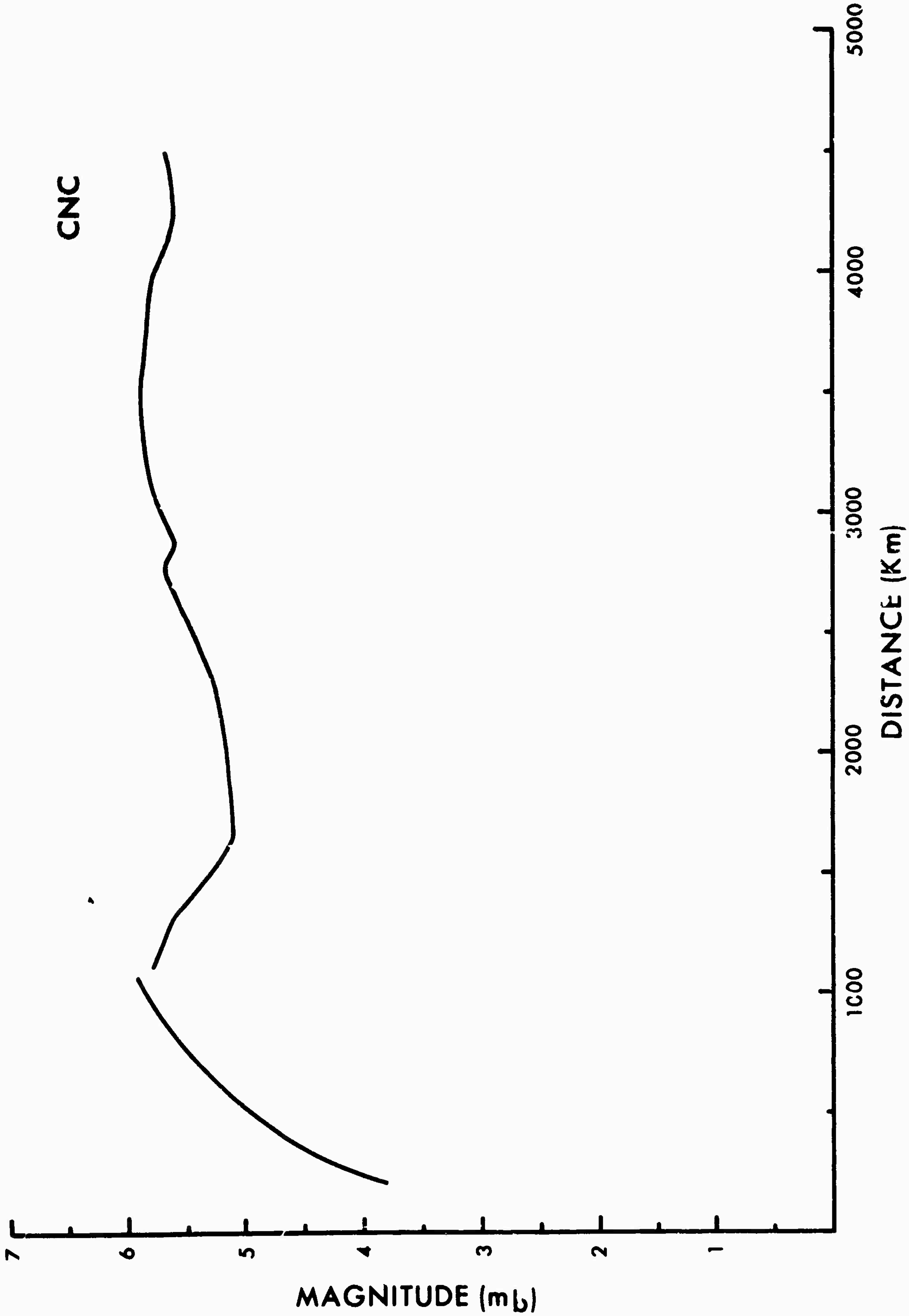
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DISTANCE (Km)
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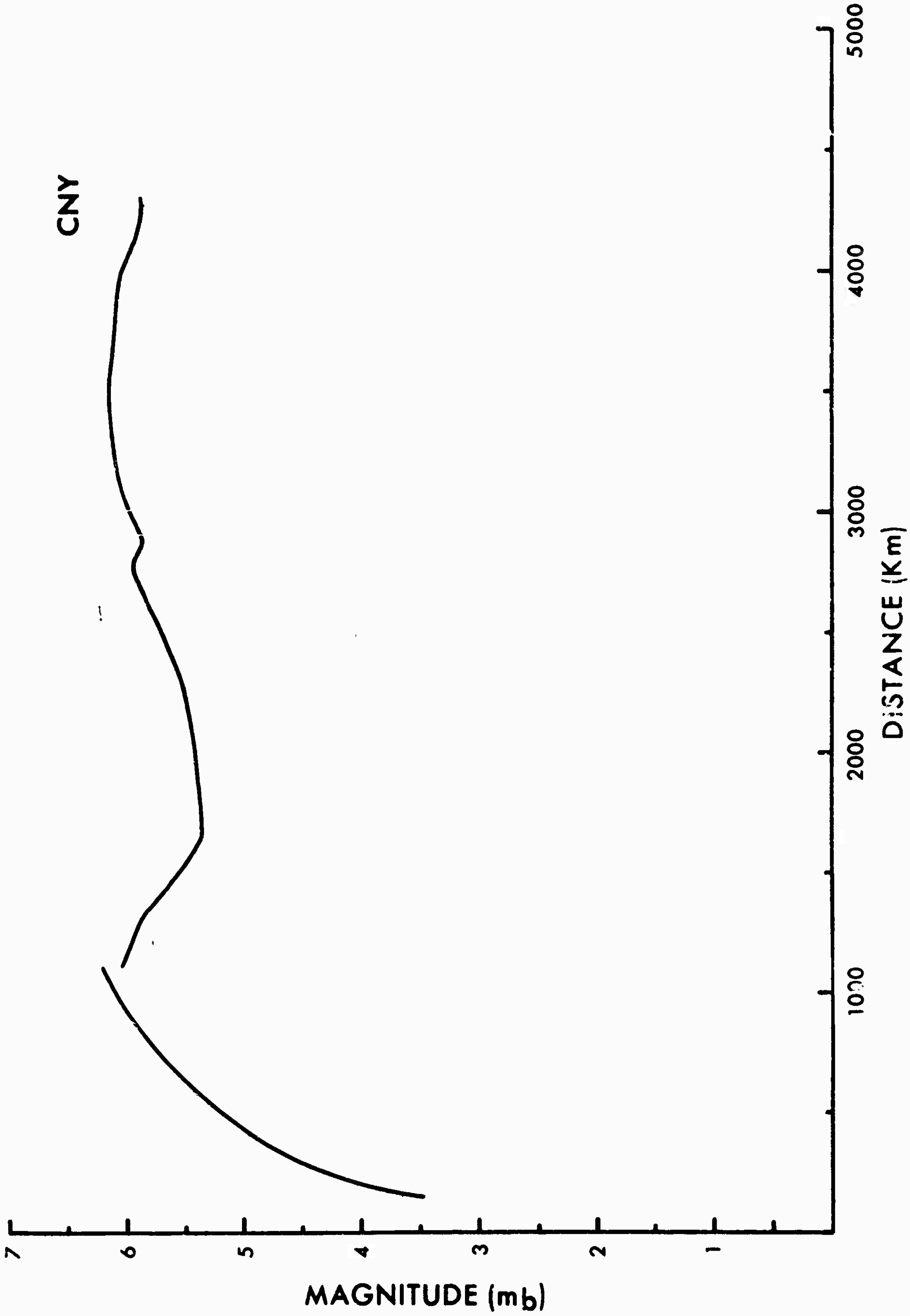
MAGNITUDE (m_b)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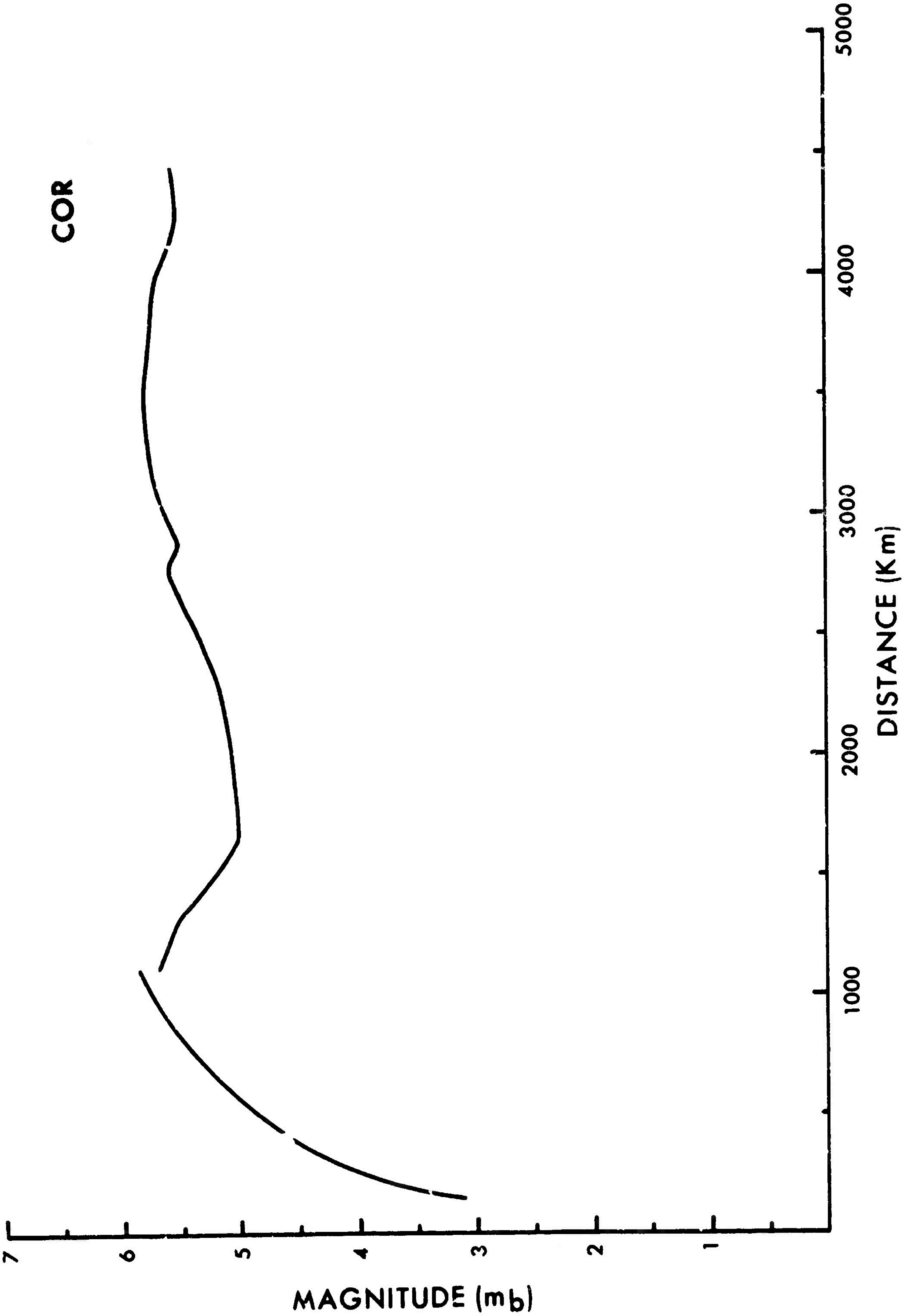
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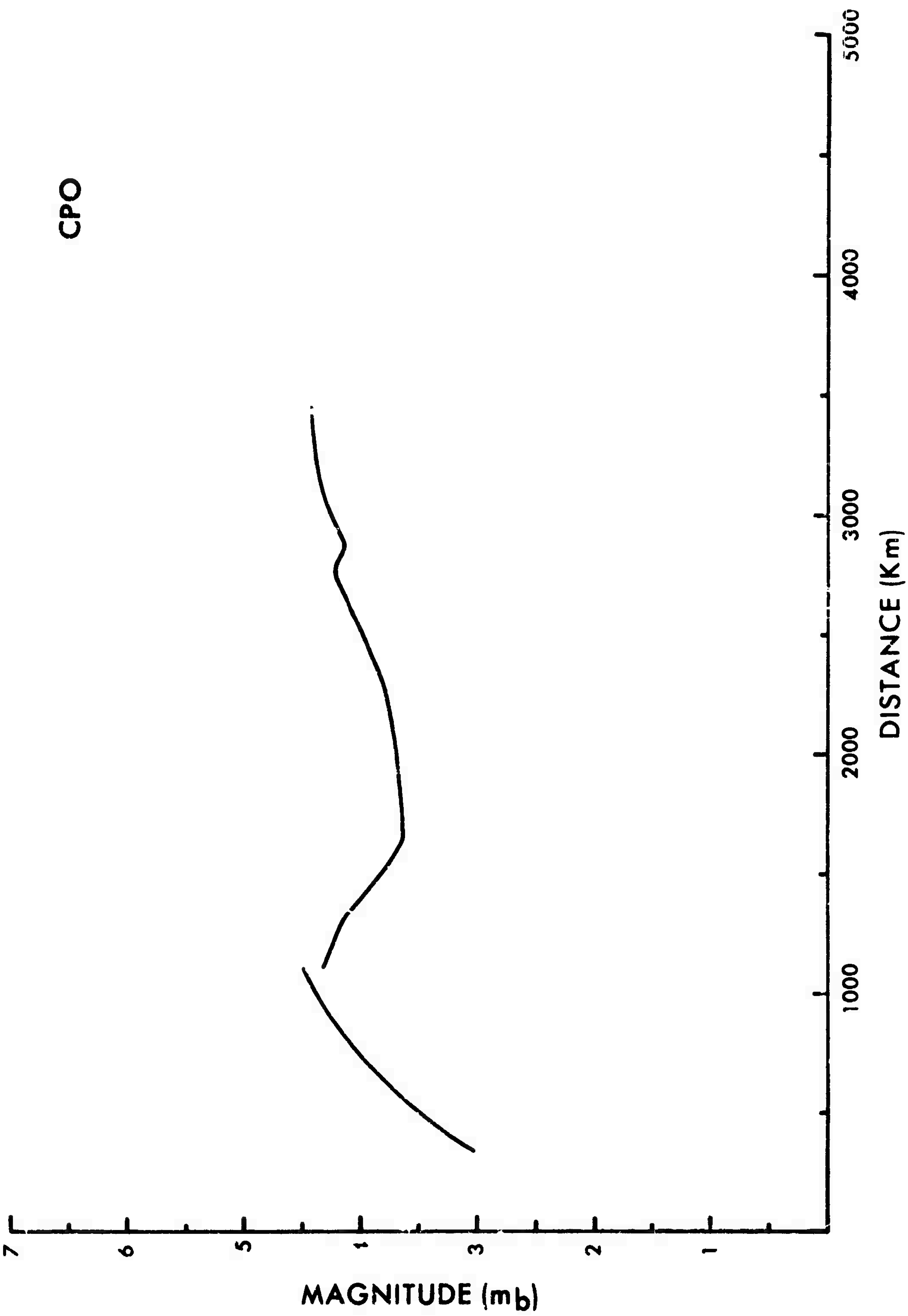
DISTANCE (Km)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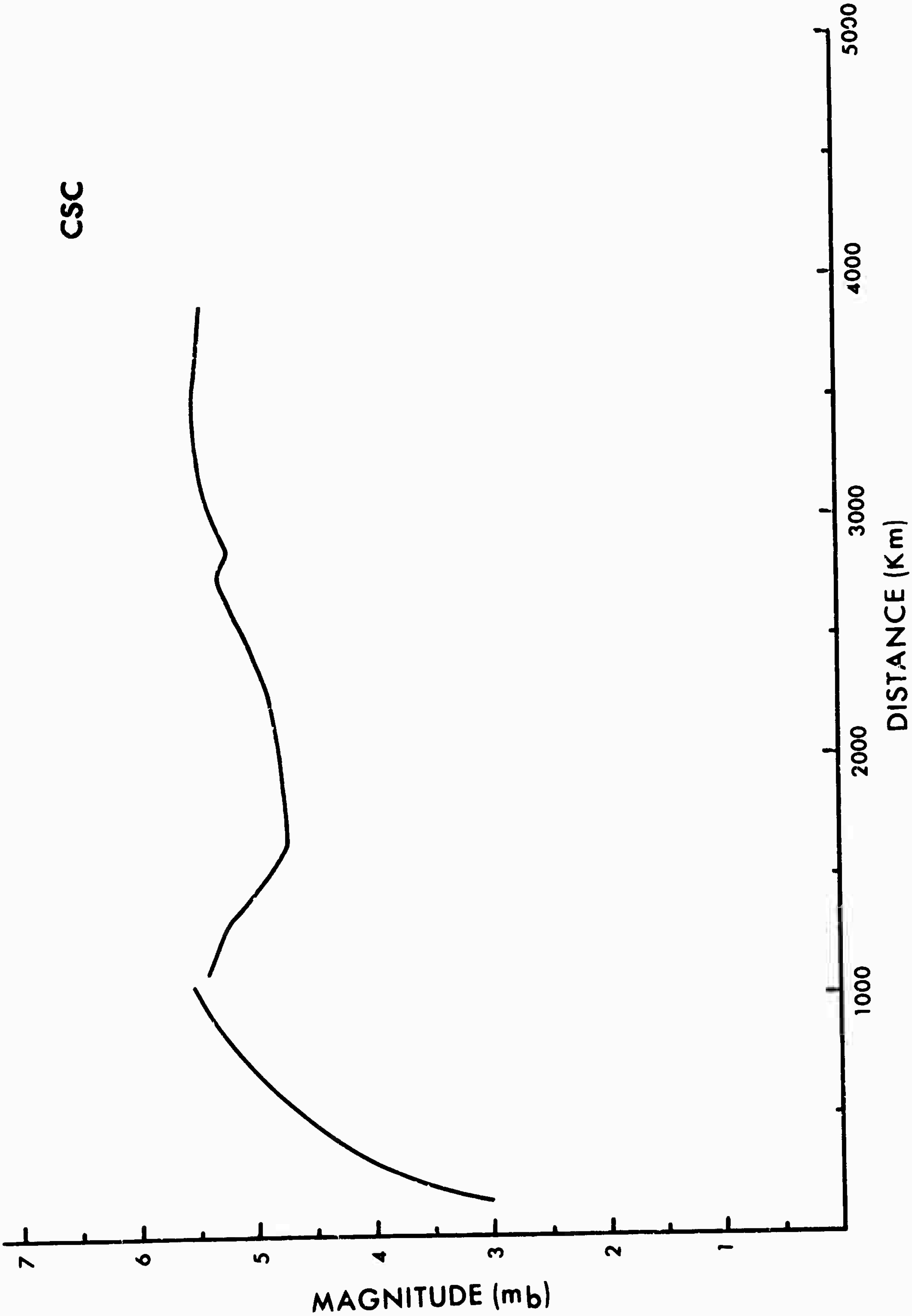

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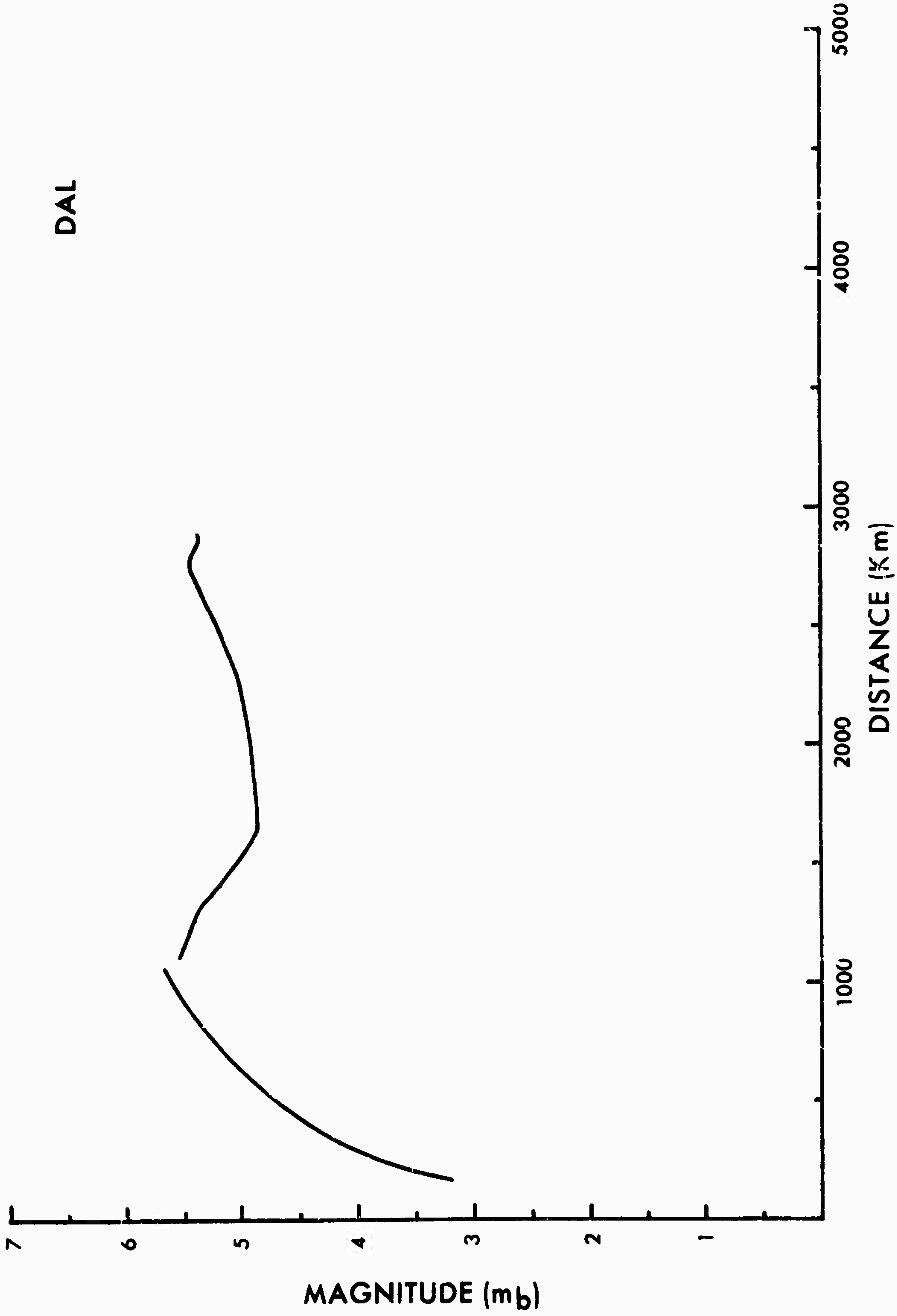
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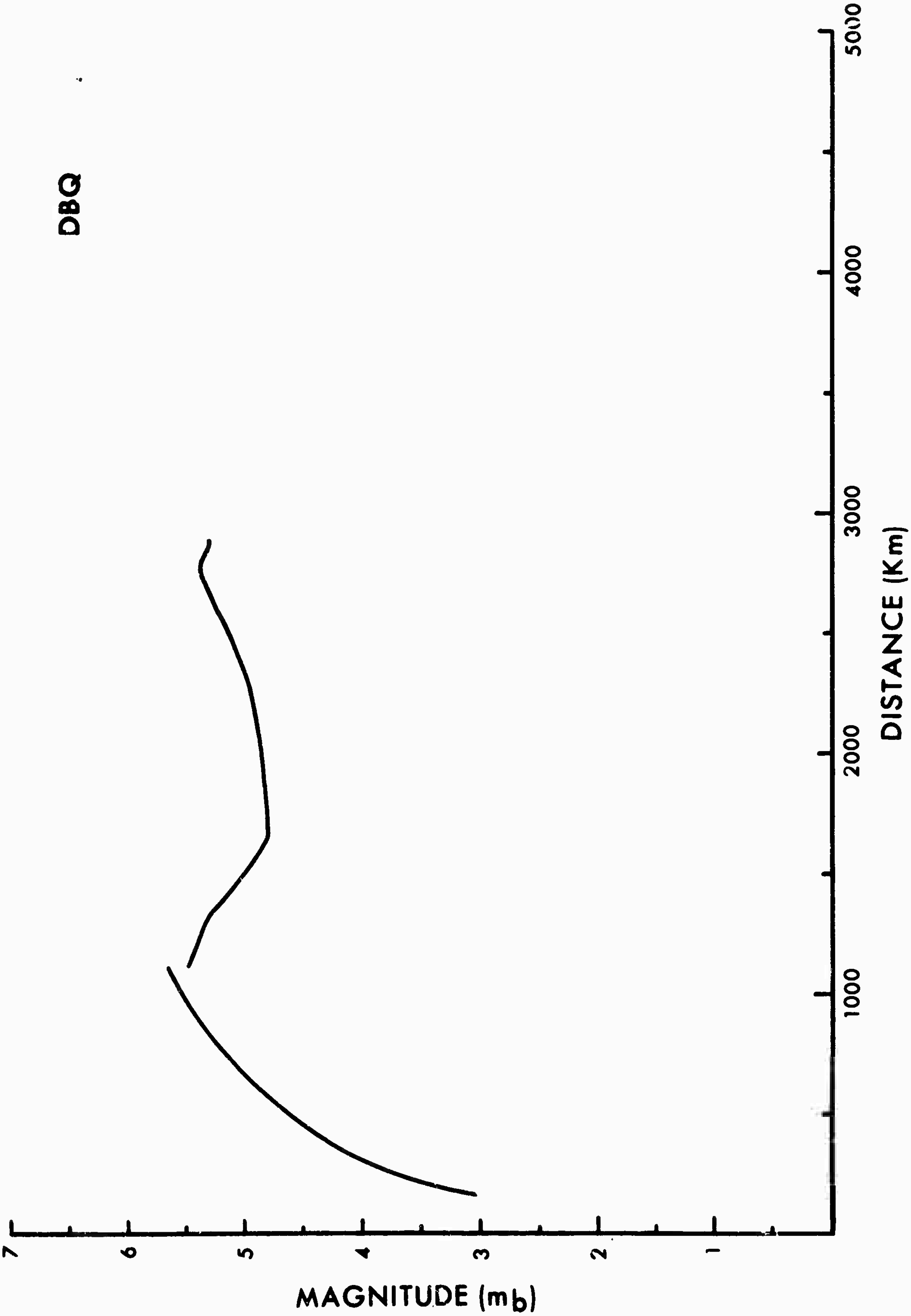
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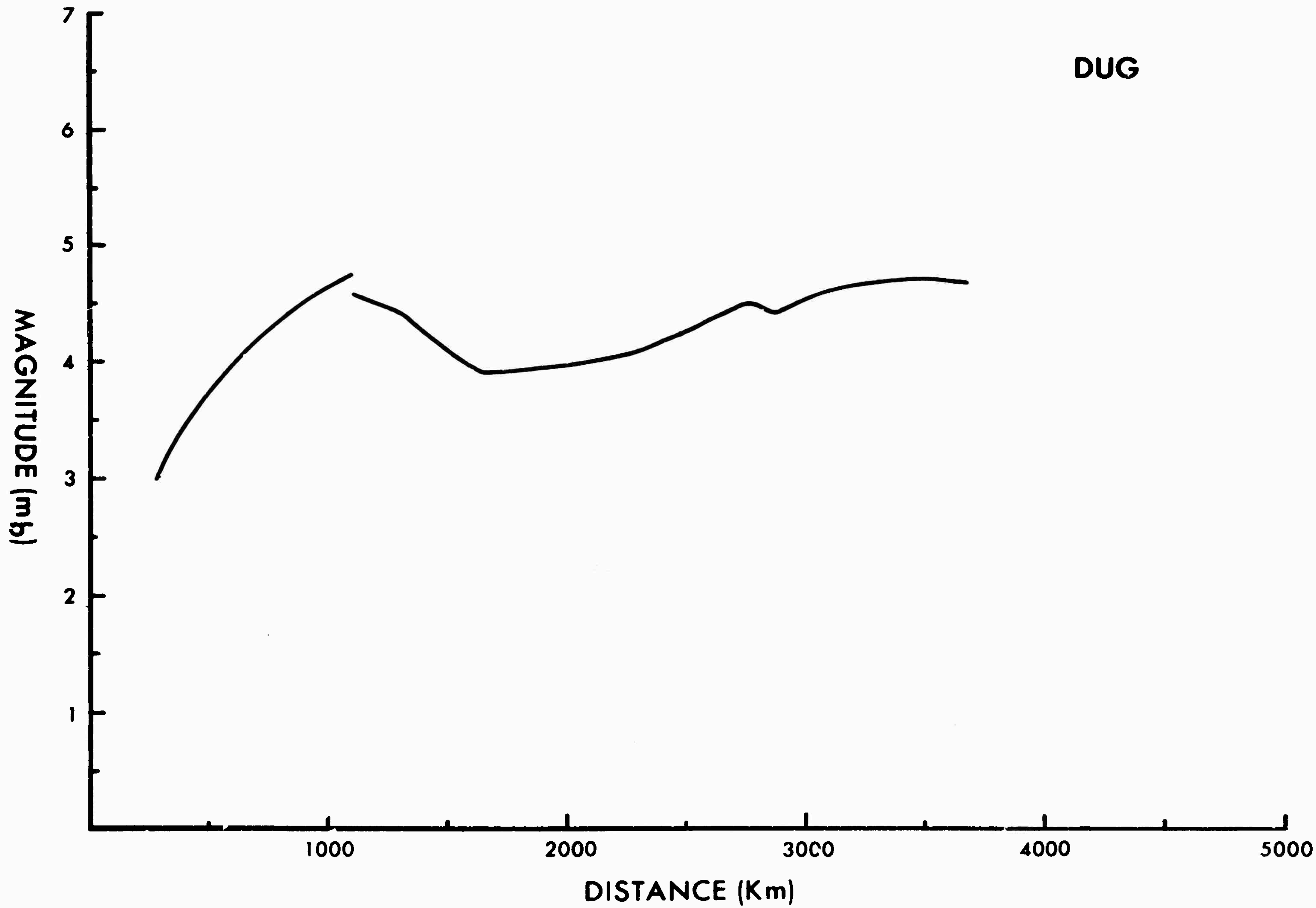
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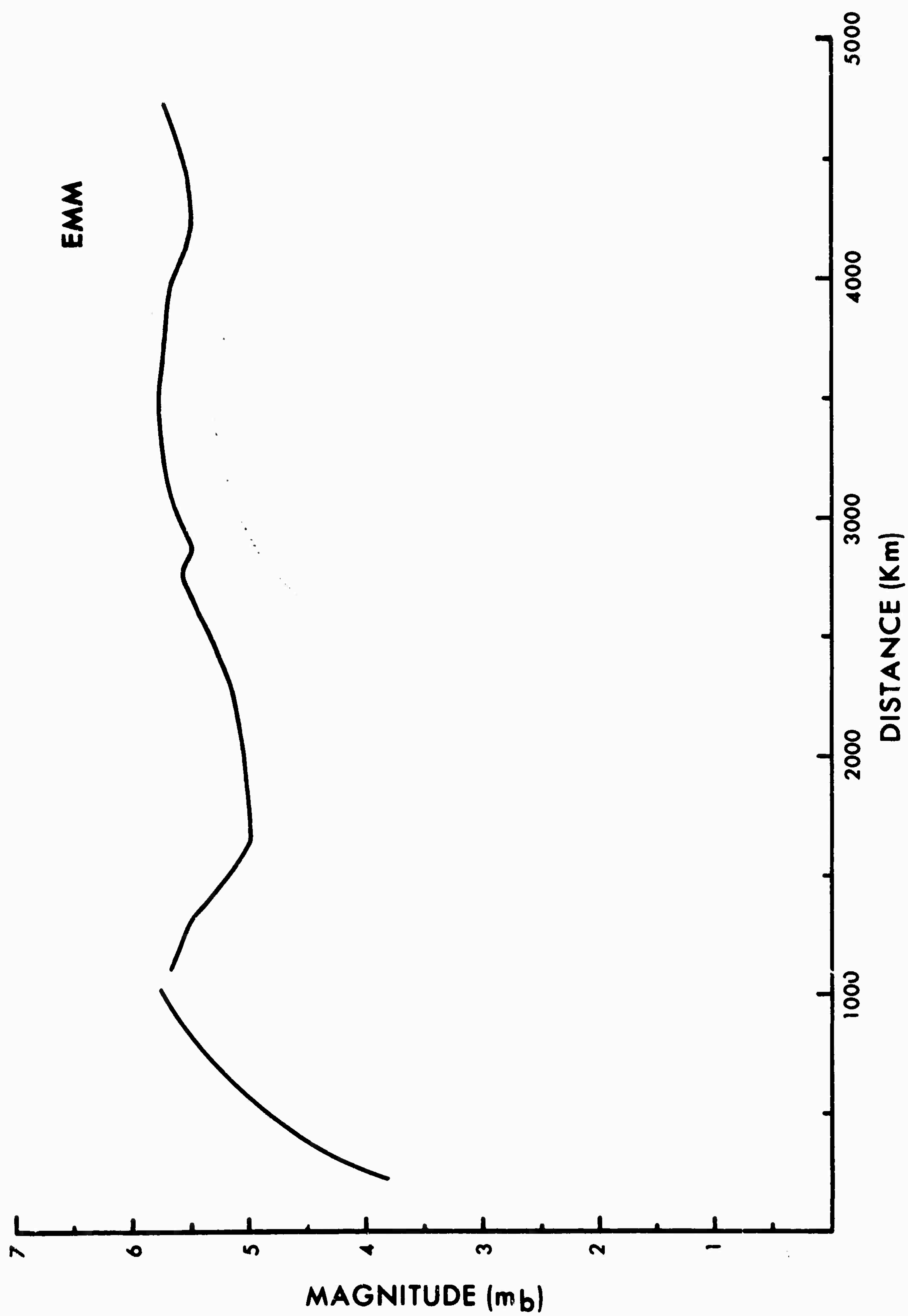
DISTANCE (Km)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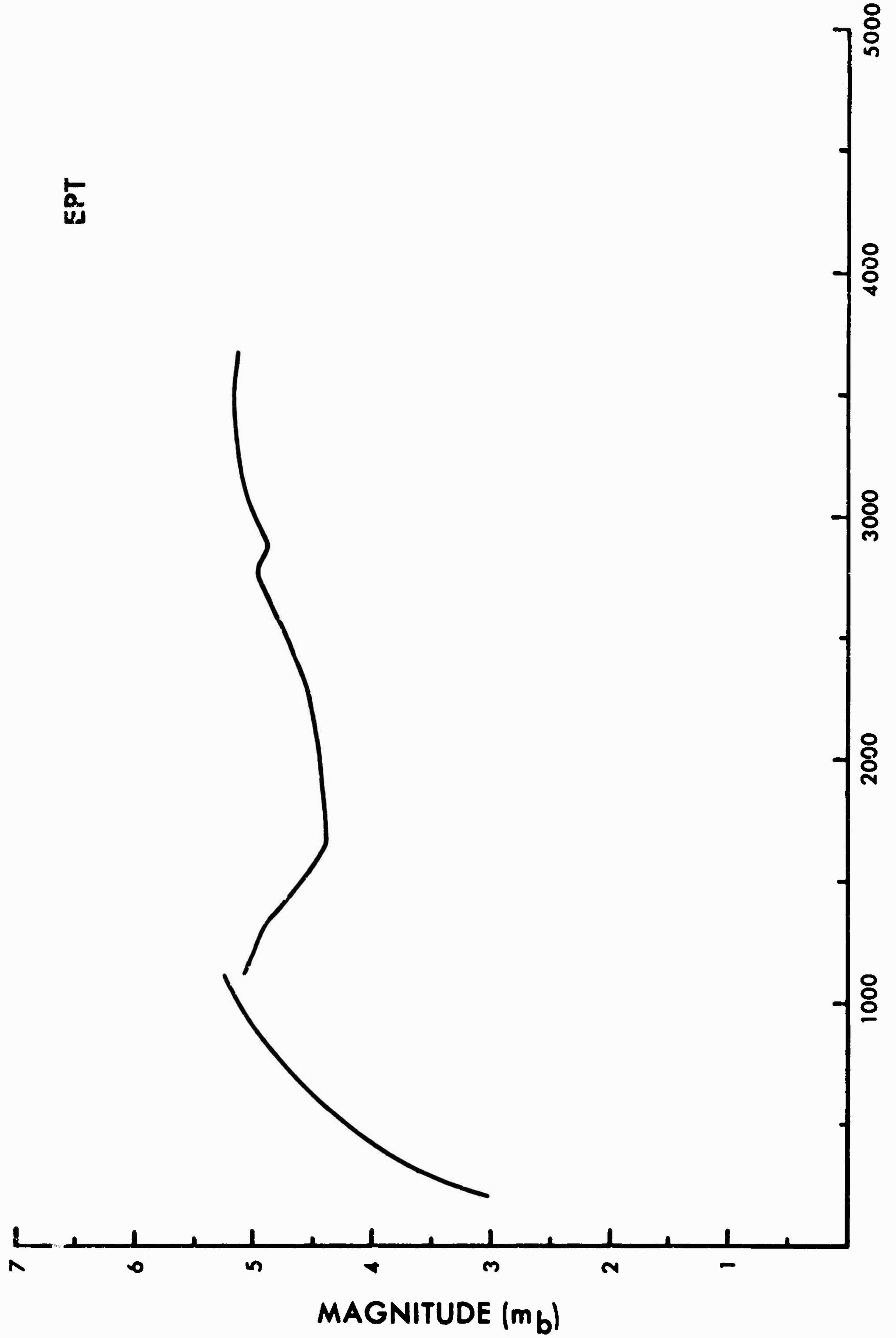
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DISTANCE (Km)
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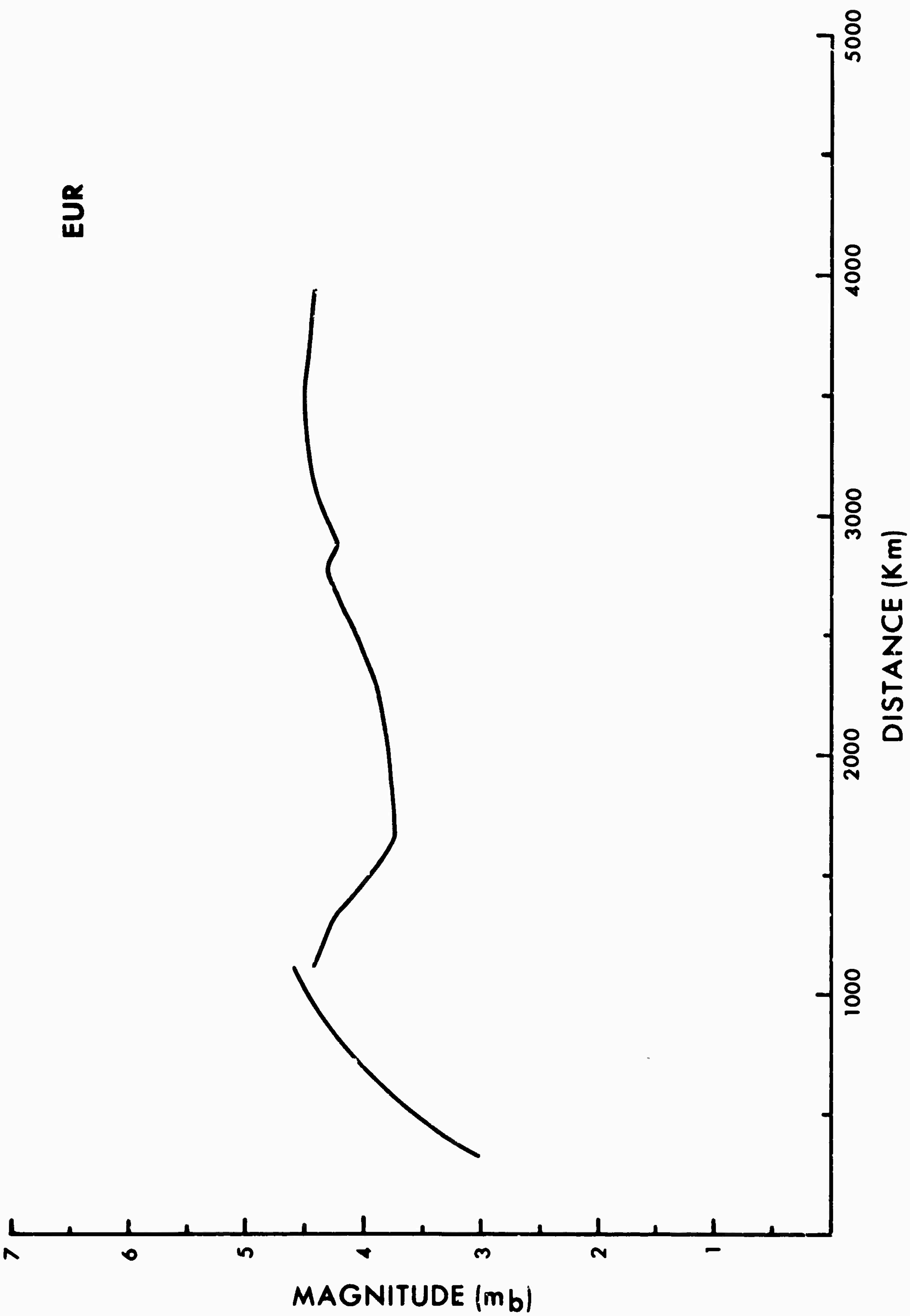
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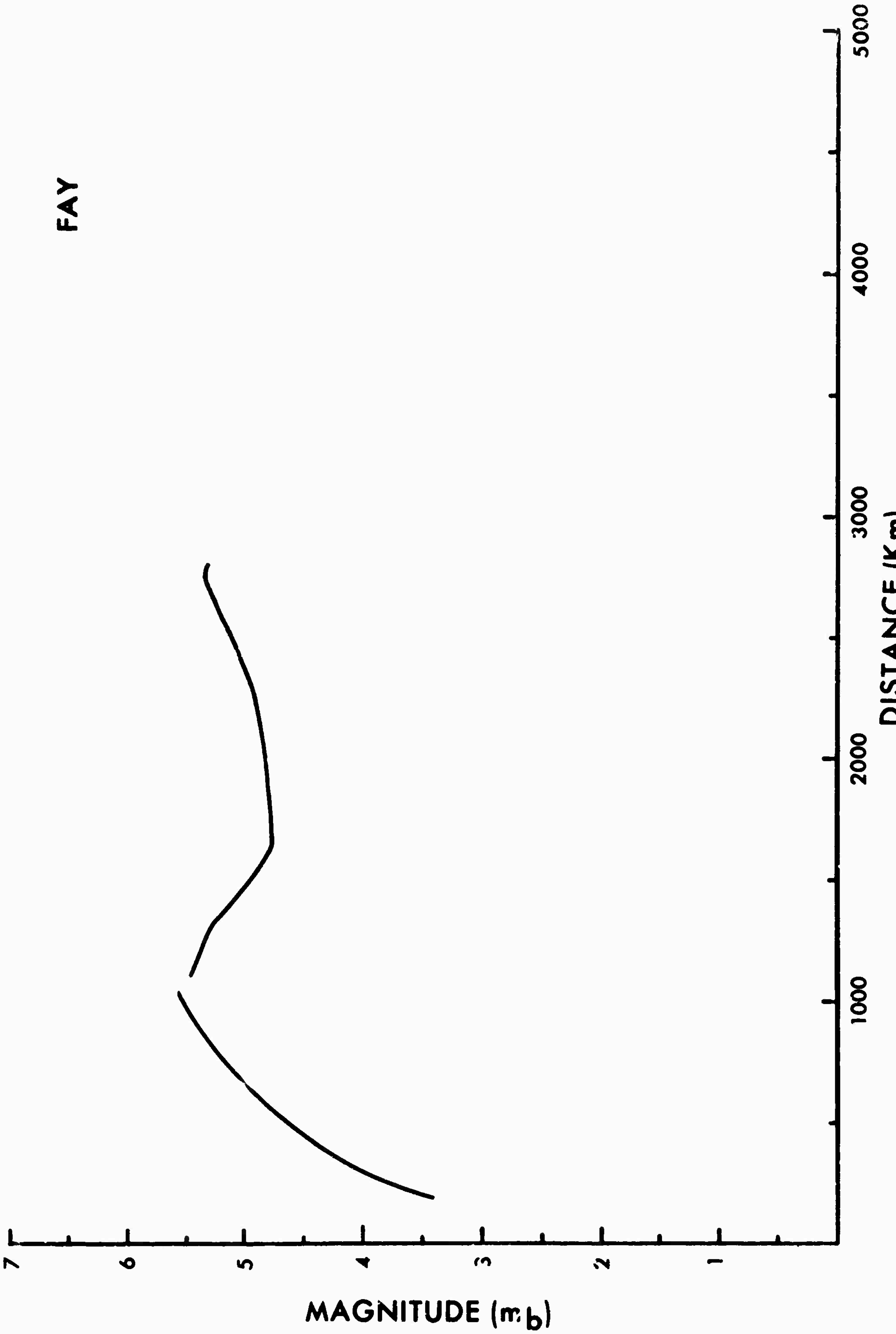
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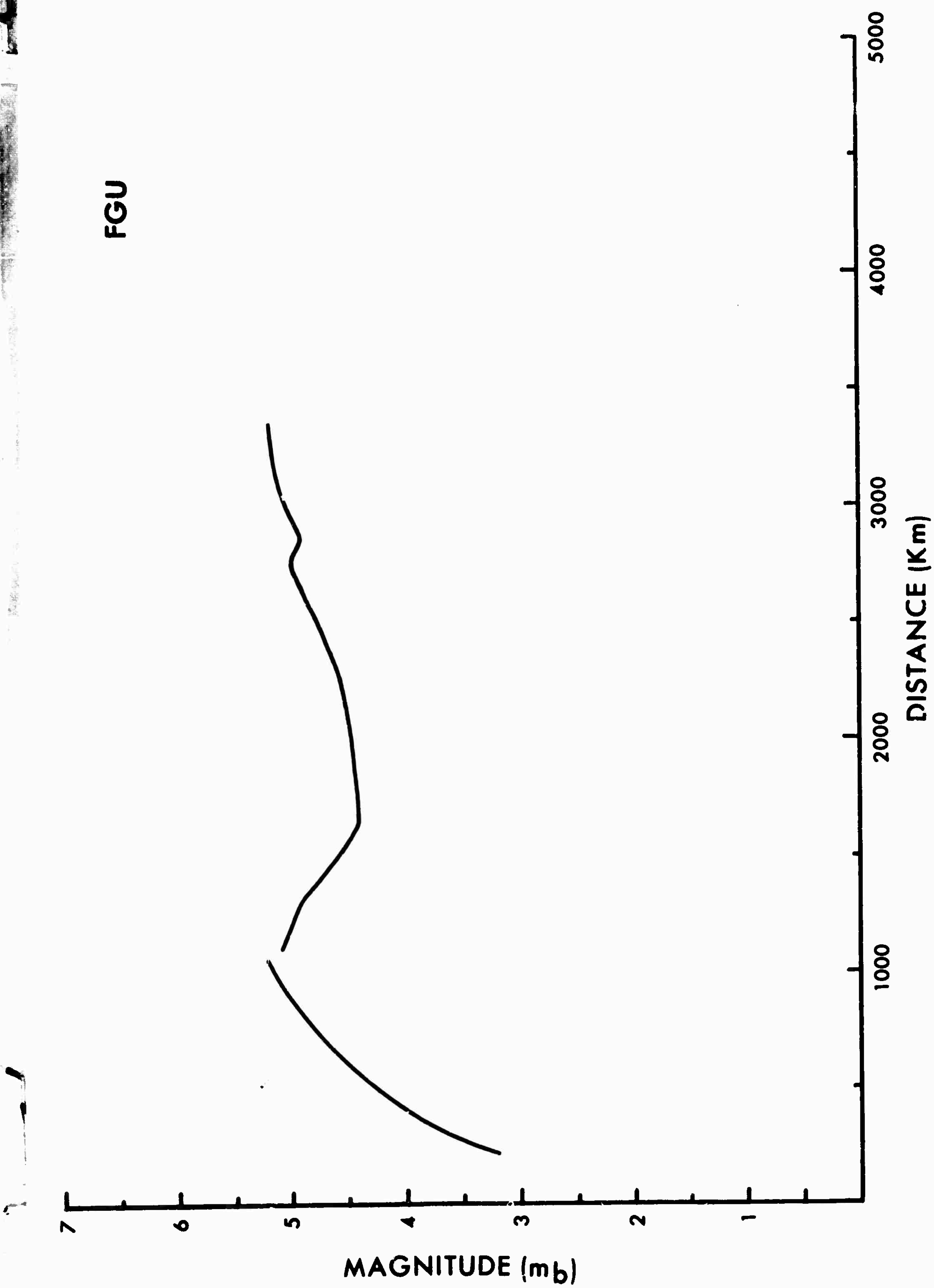
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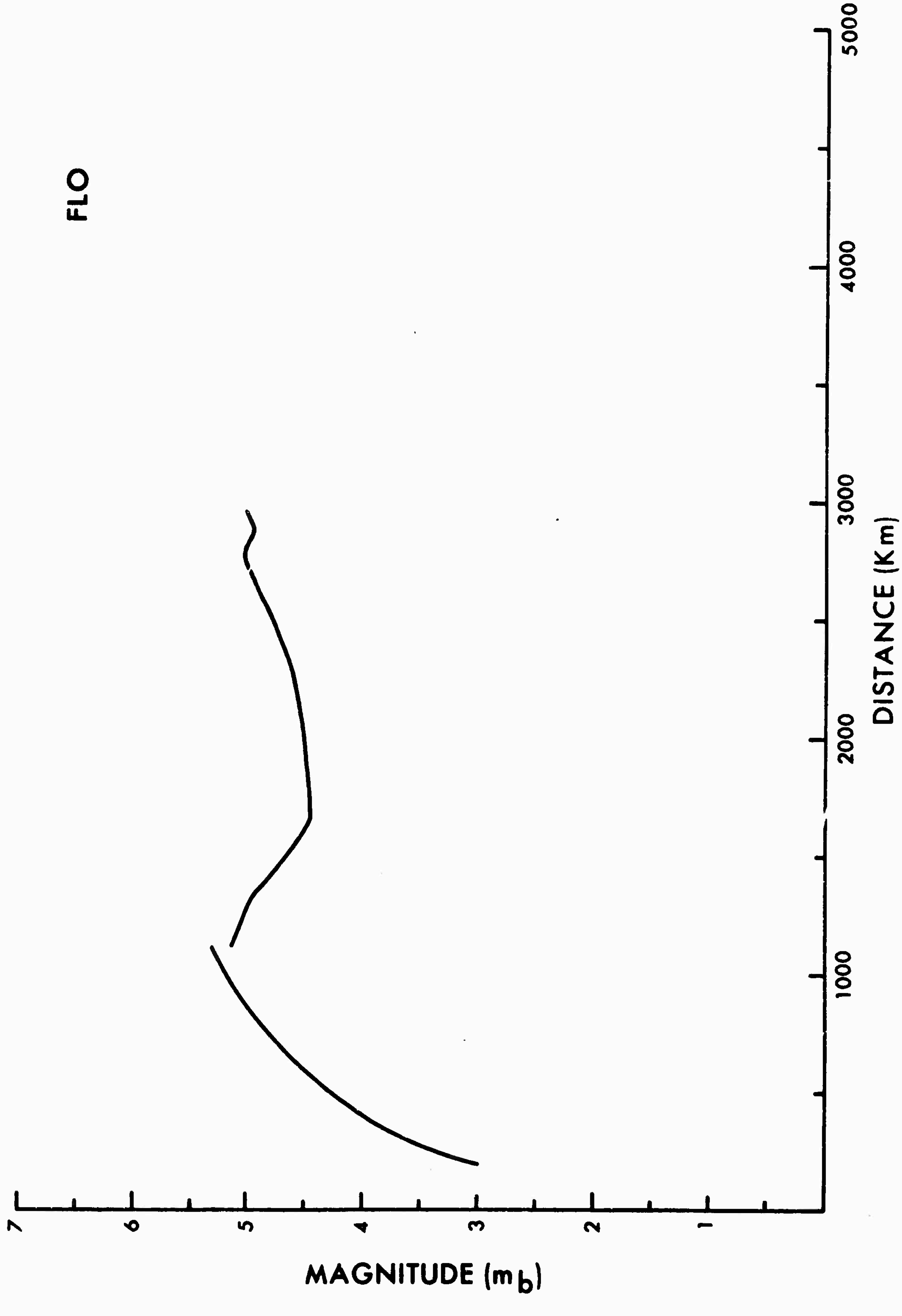
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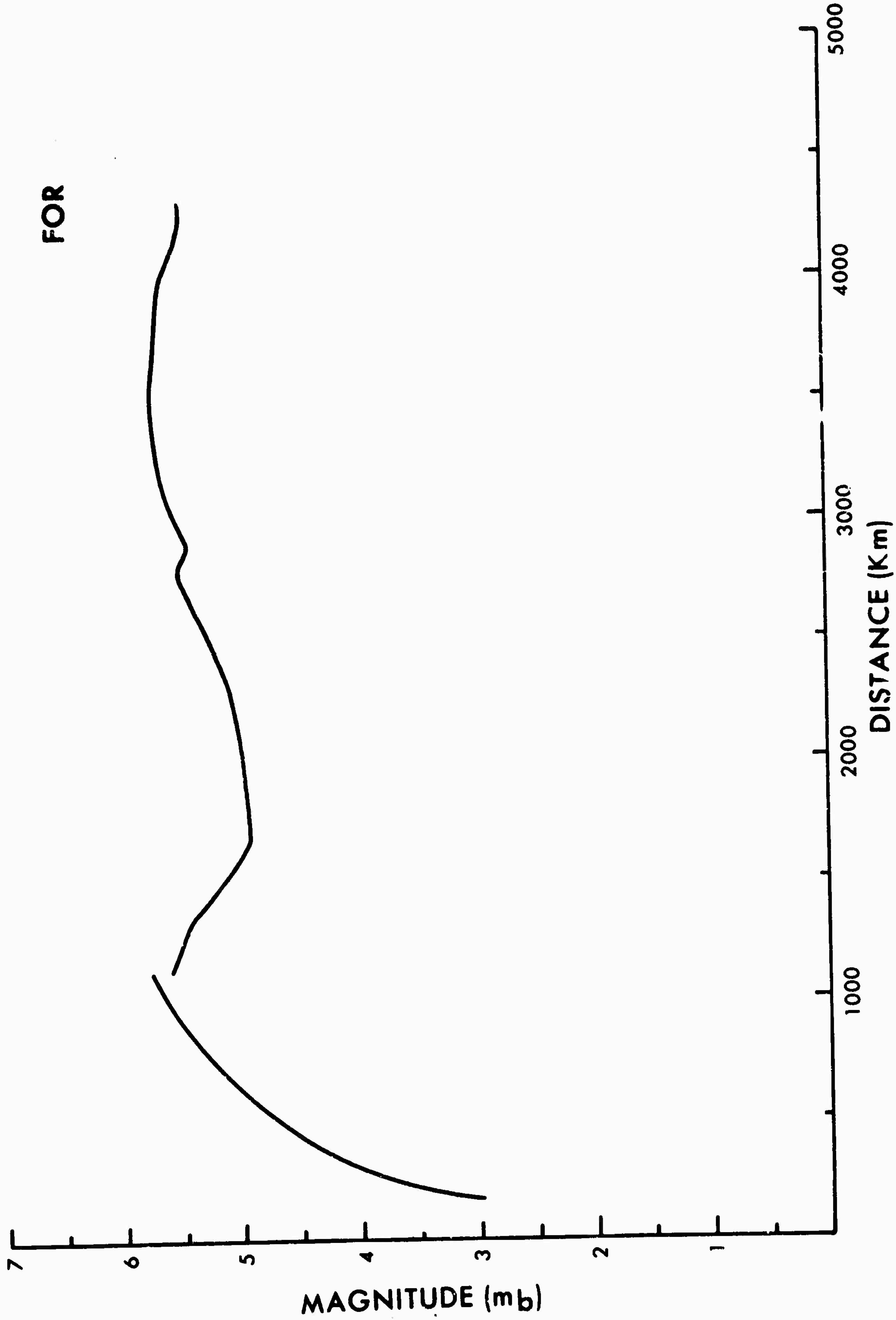
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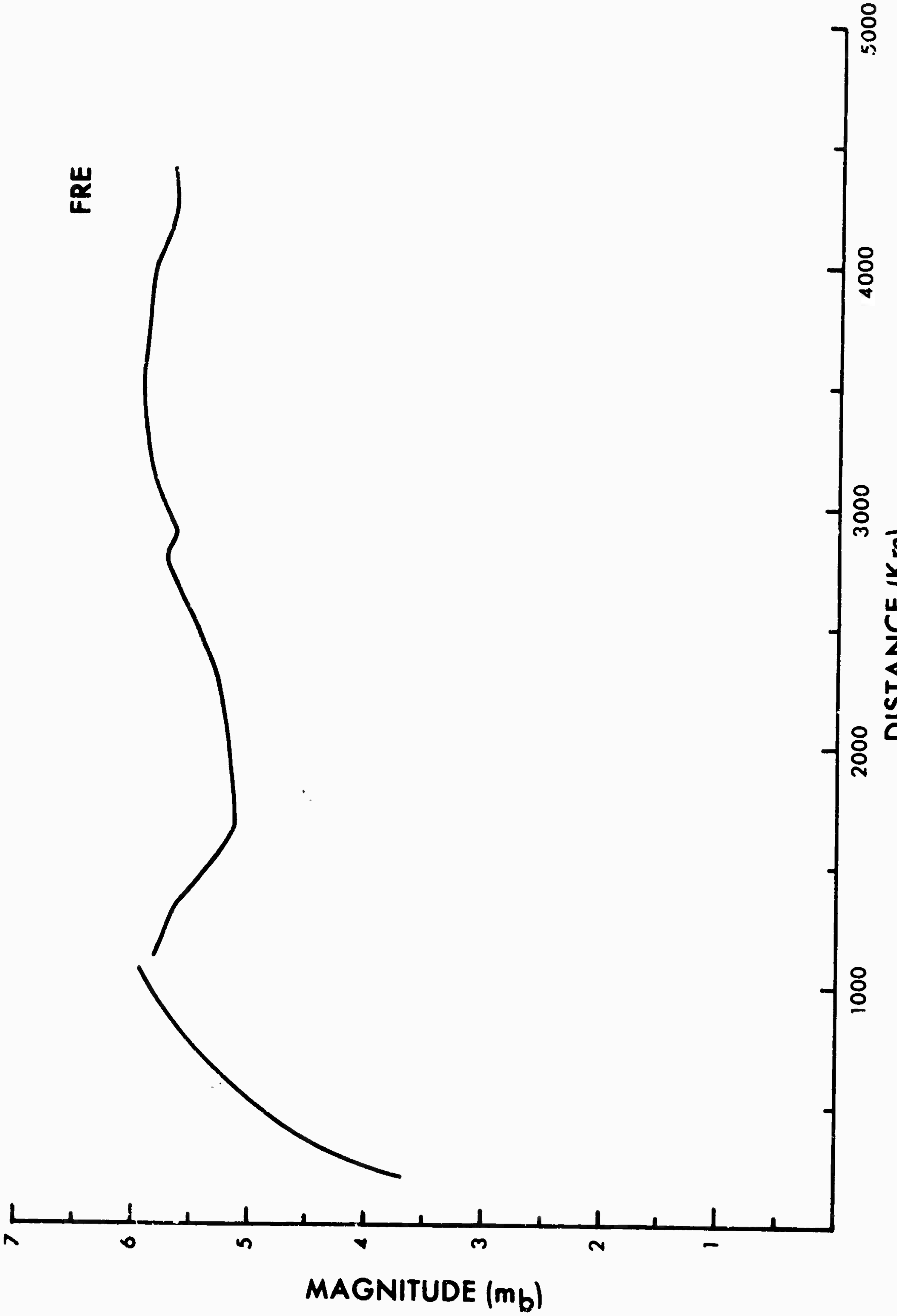
MAGNITUDE (mb)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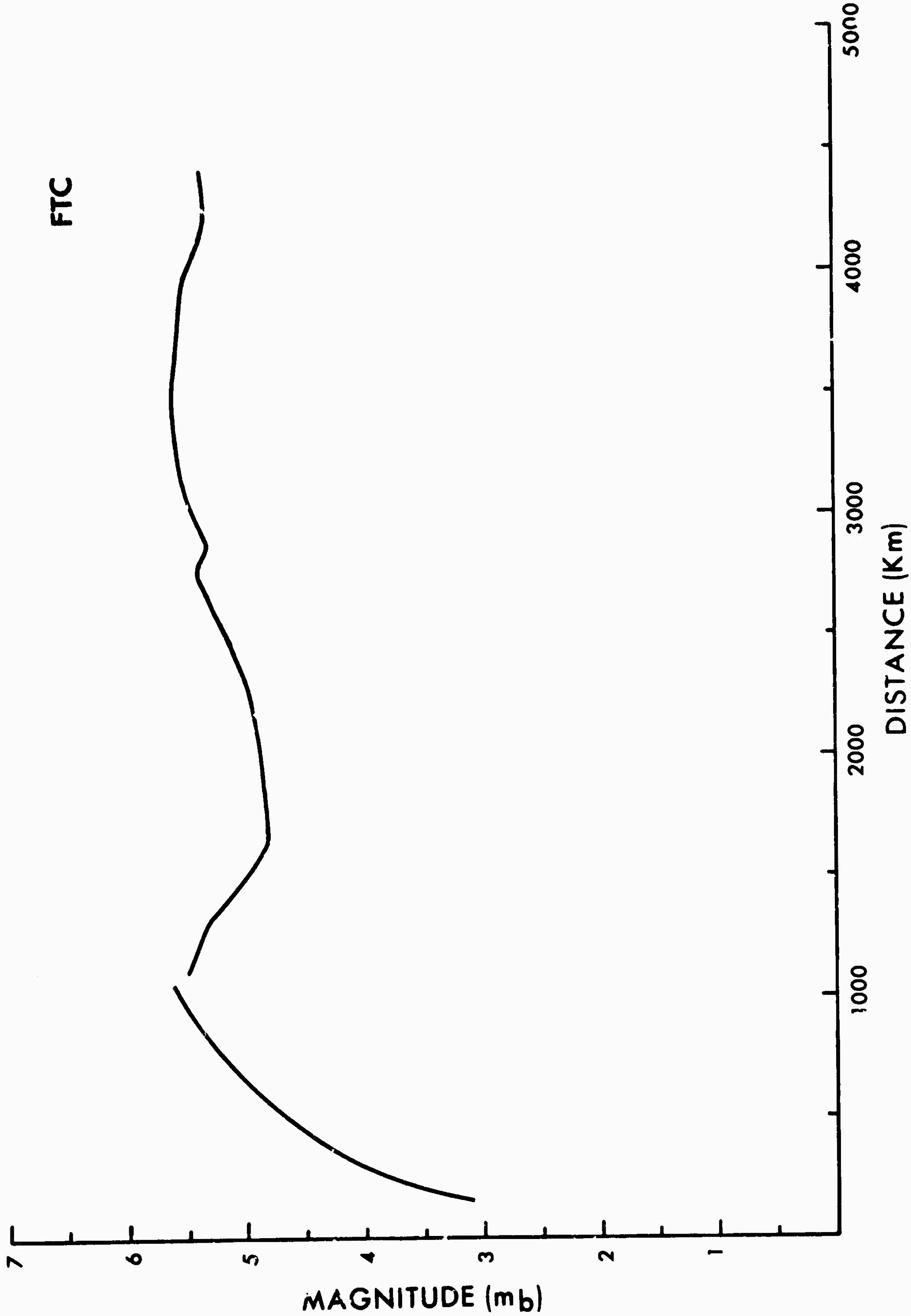
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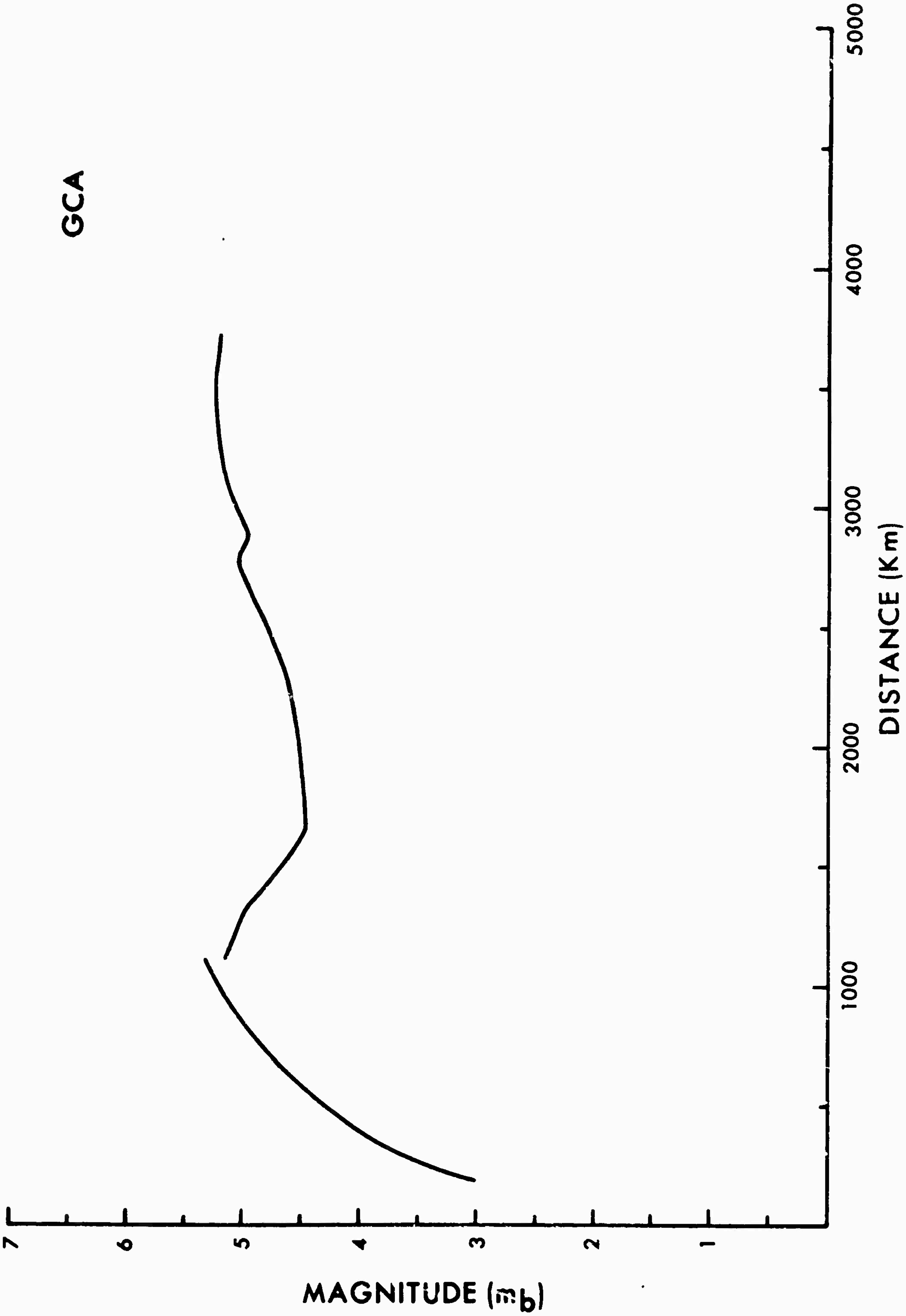
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DISTANCE (Km)
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MAGNITUDE (mb)
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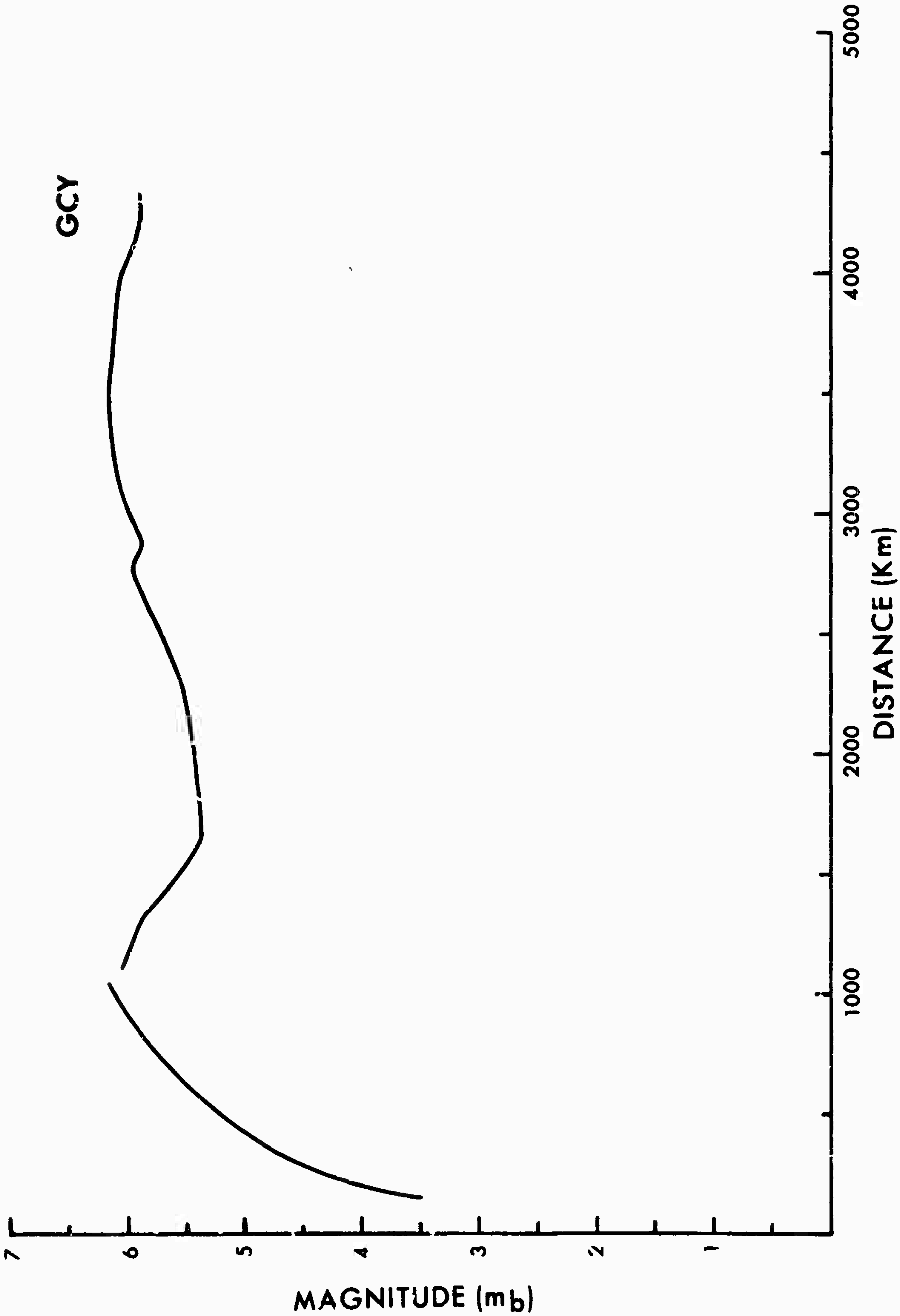
GCY
MAGNITUDE (mb)
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2
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DISTANCE (Km)
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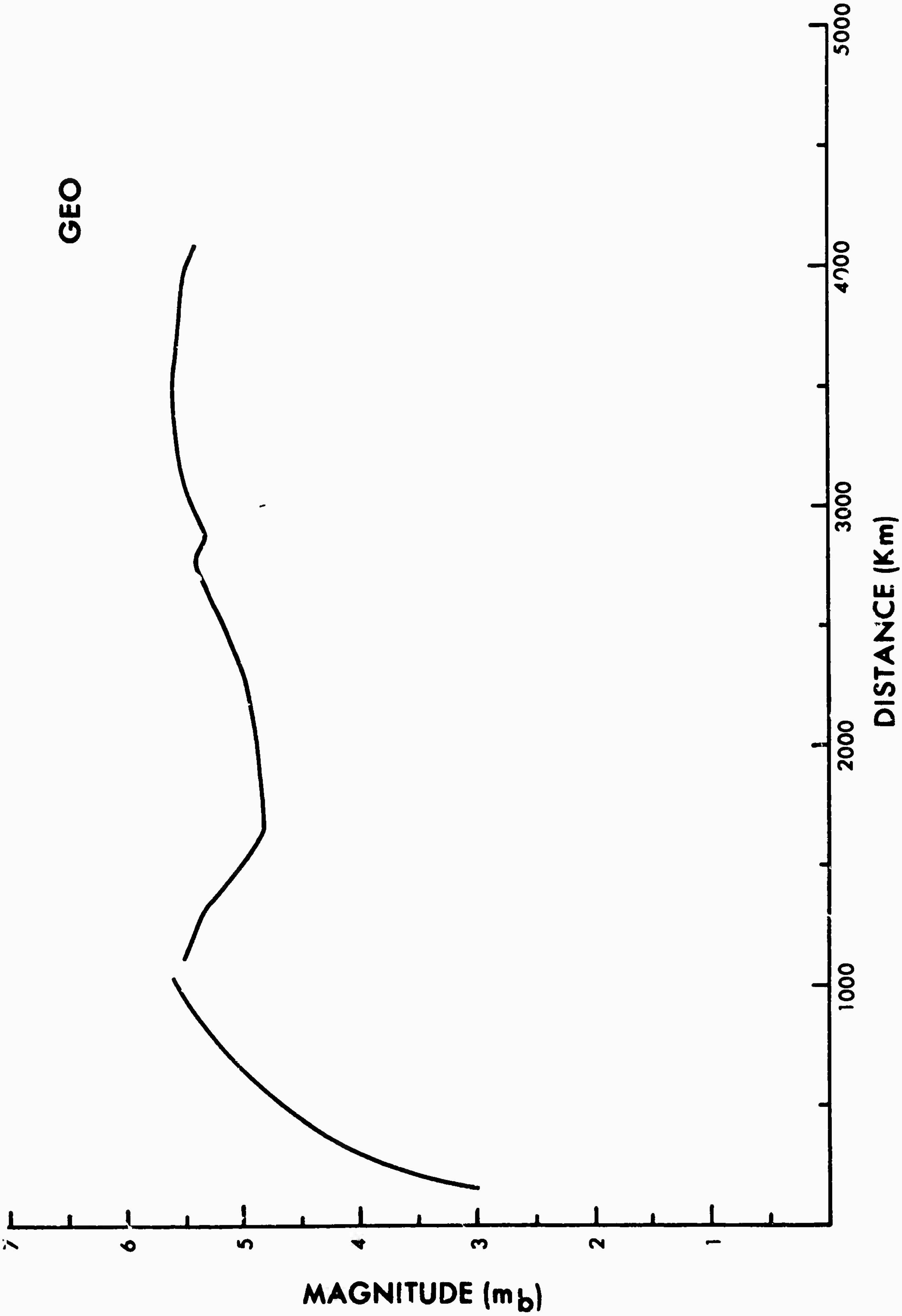
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MAGNITUDE (m_b)
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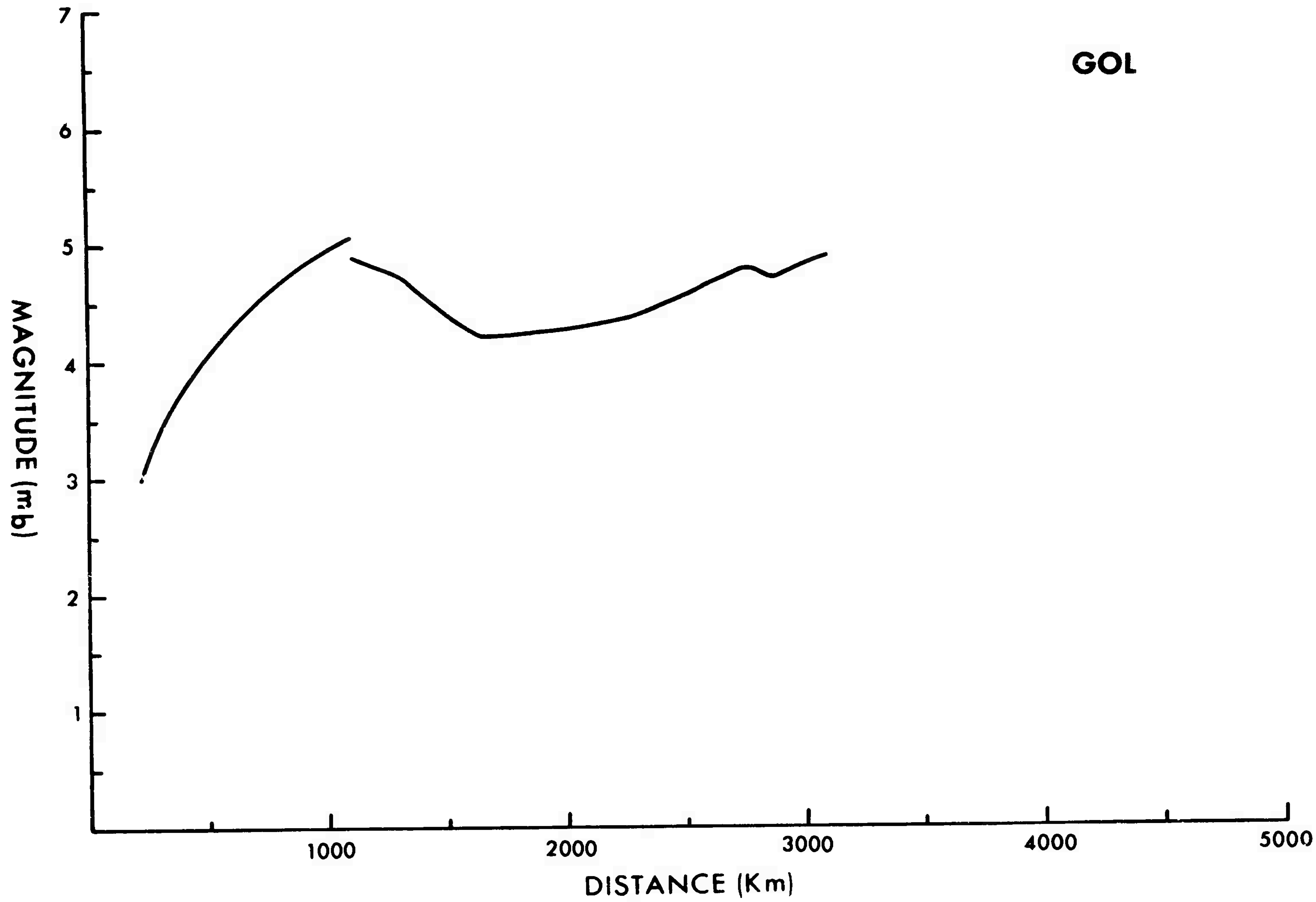
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MAGNITUDE (m_b)
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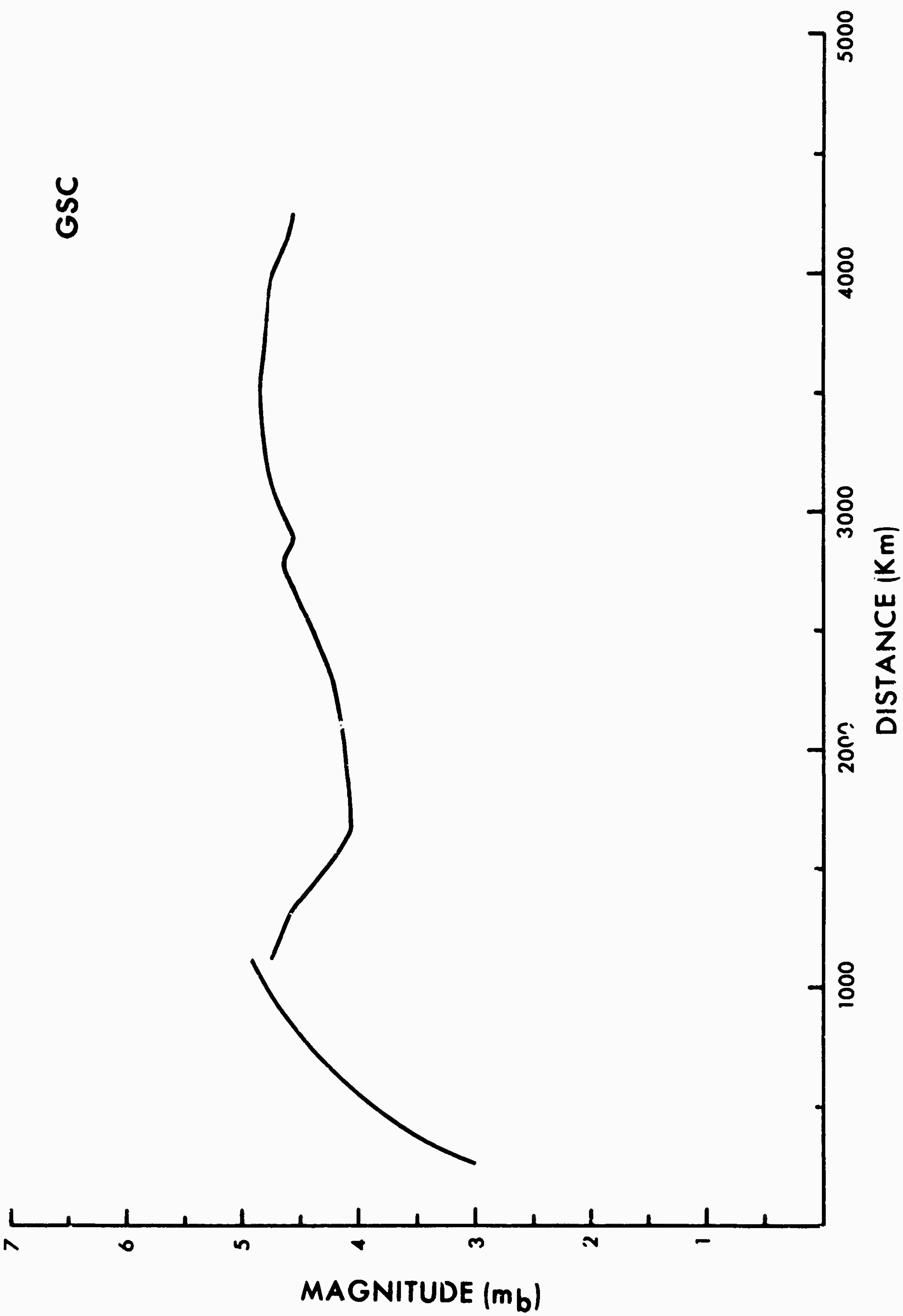
DISTANCE (Km)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MAGNITUDE (m_b)
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4
3
2
1
DISTANCE (Km)
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2000
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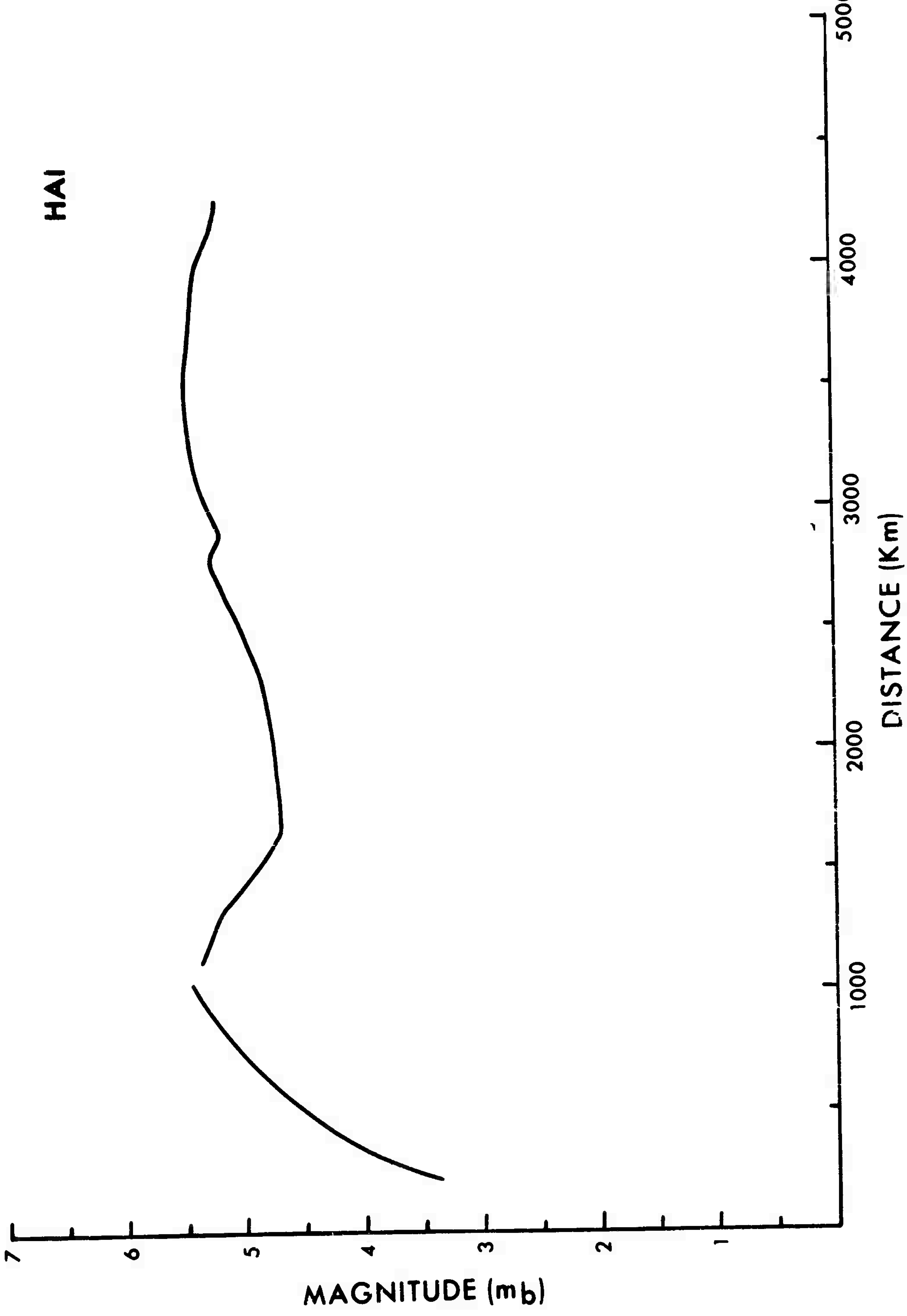
4000
5000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DISTANCE (Km)
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5000
MAGNITUDE (mb)
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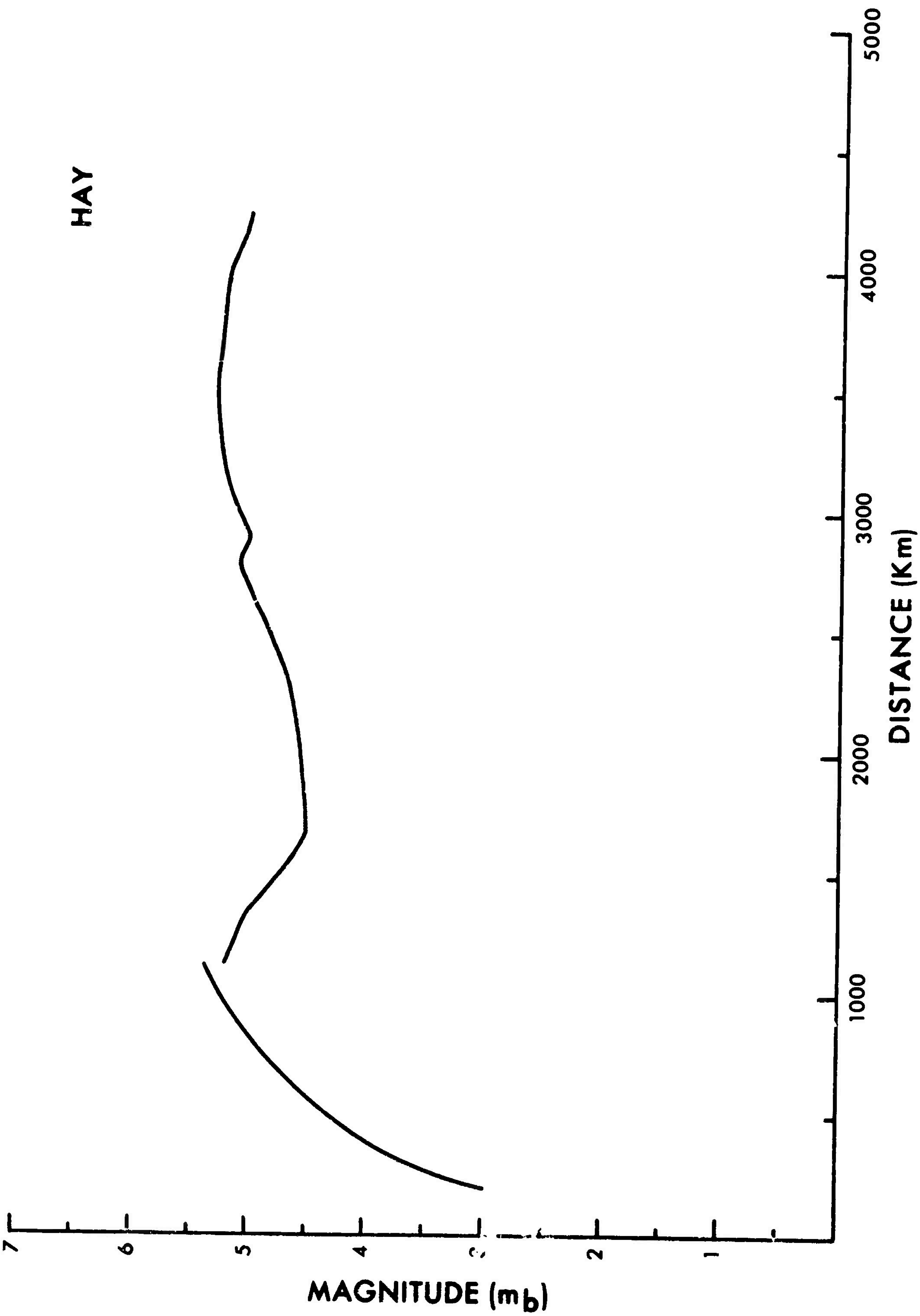
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MAGNITUDE (m_b)
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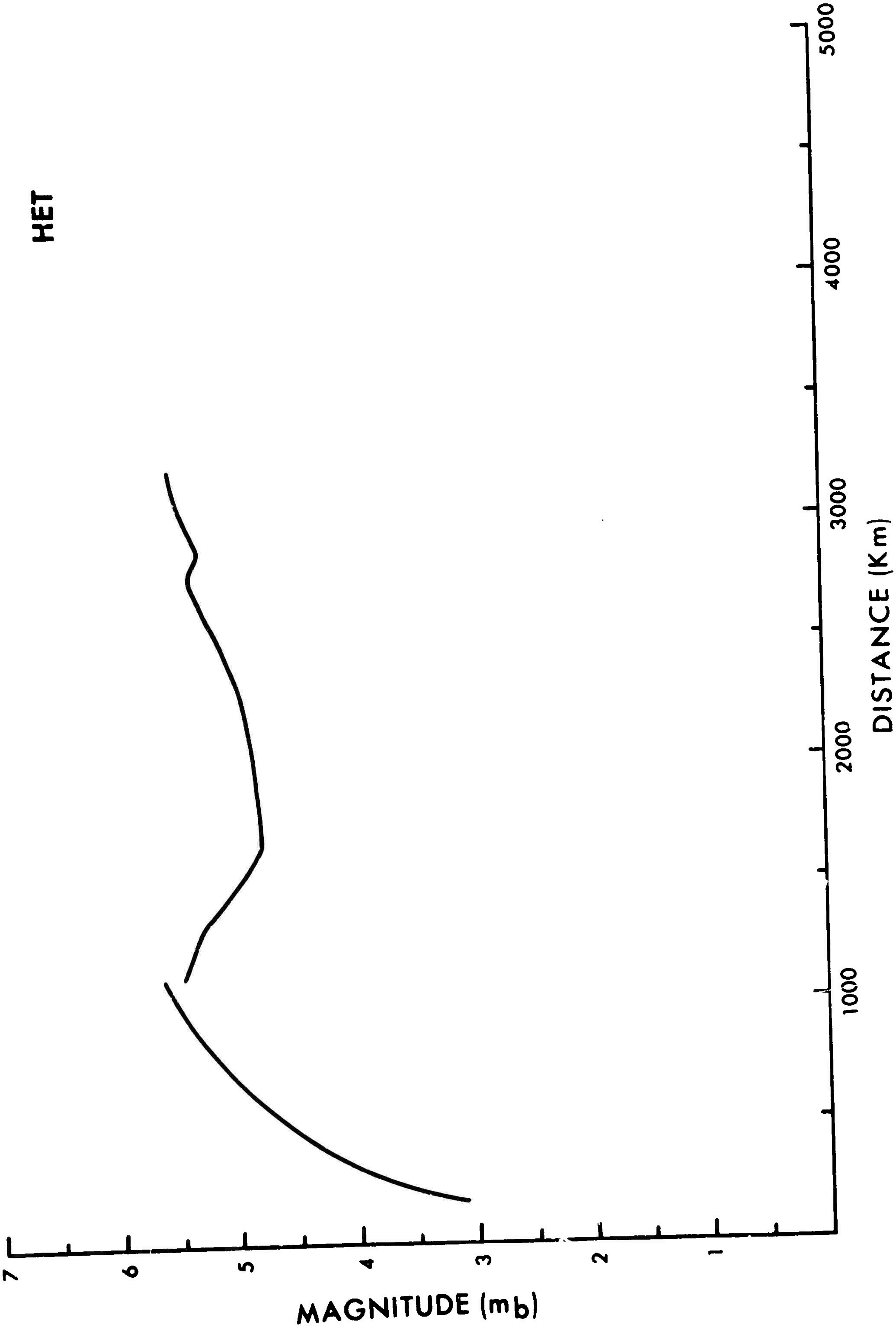
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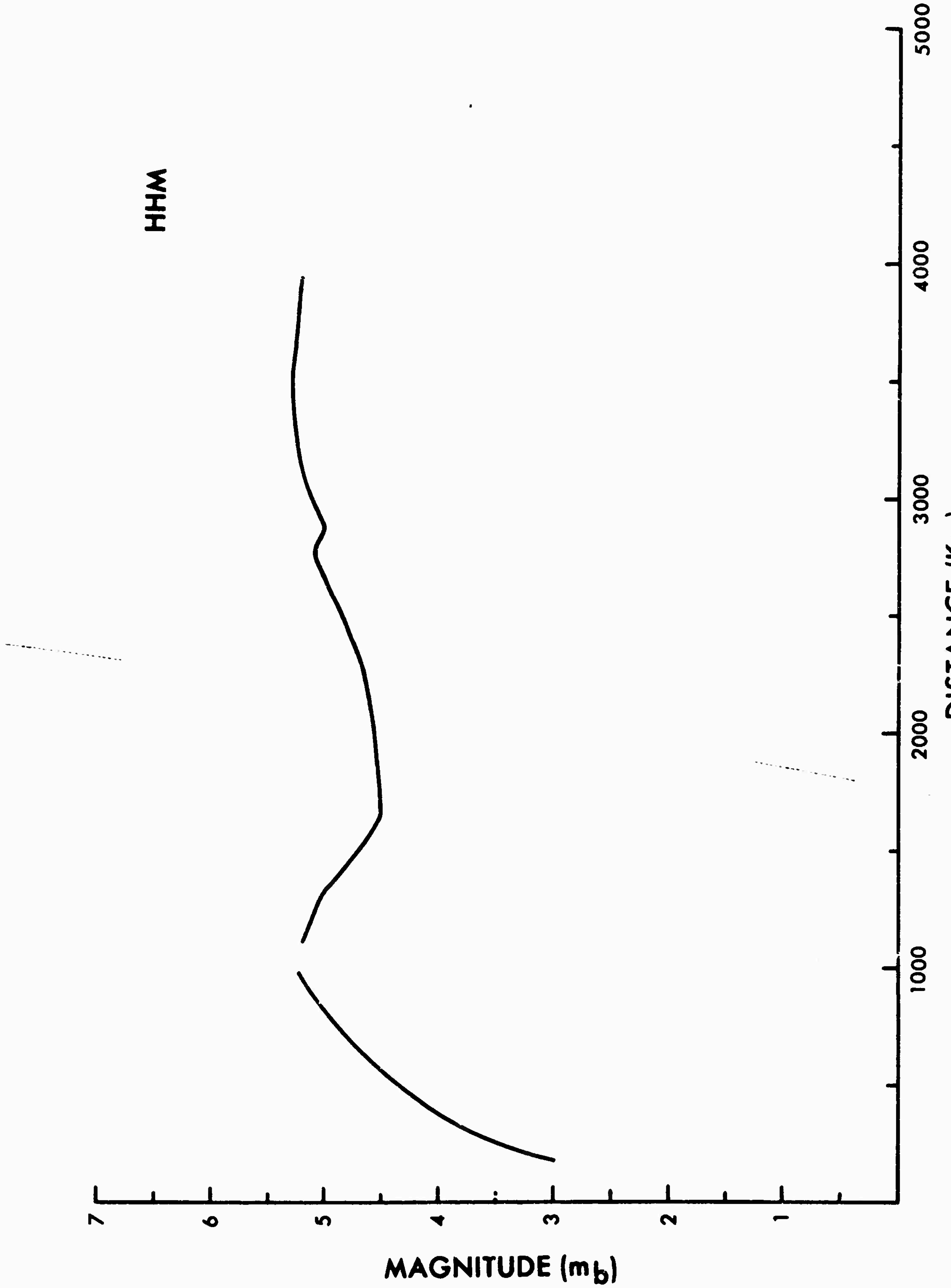

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DISTANCE (Km)
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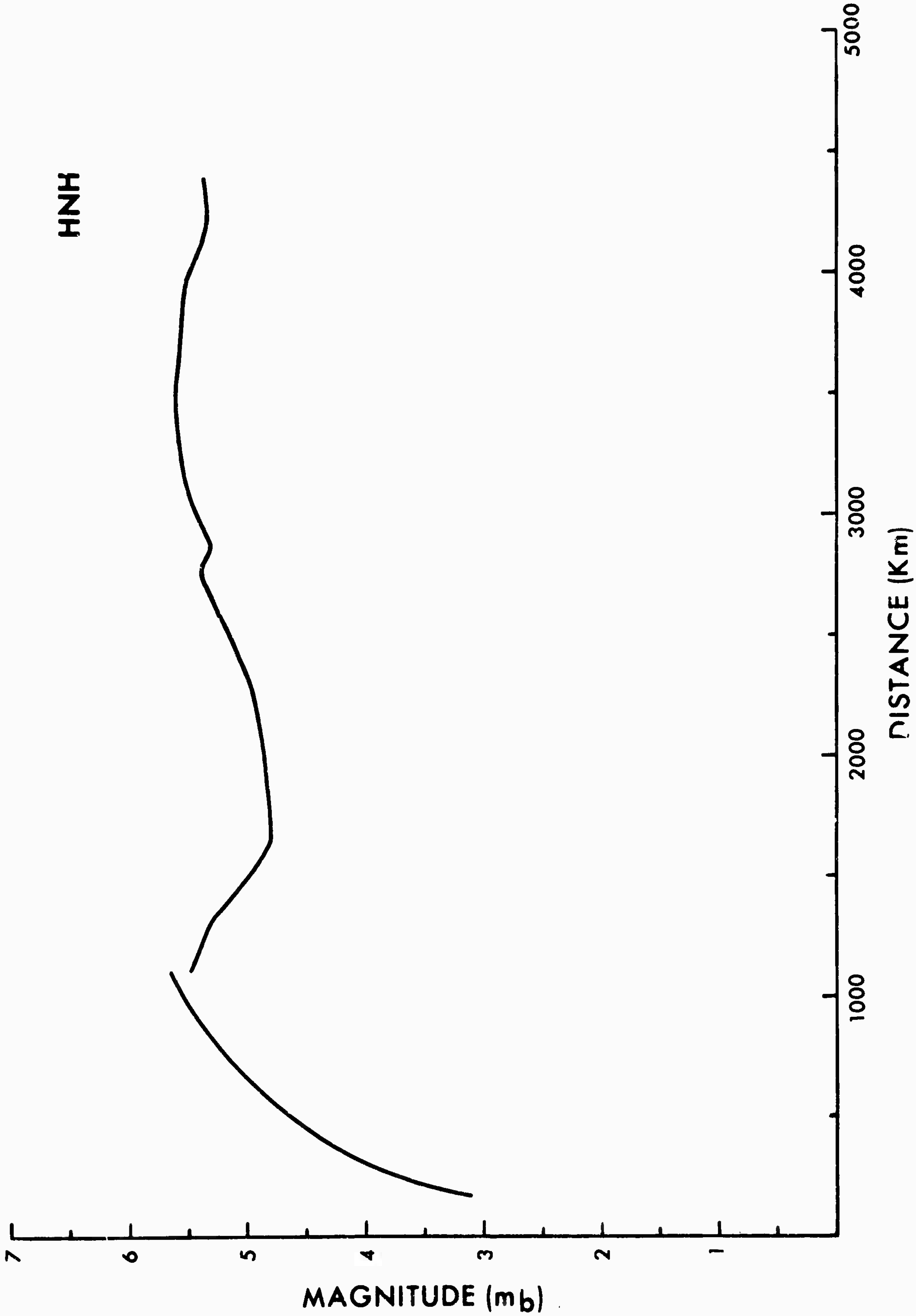
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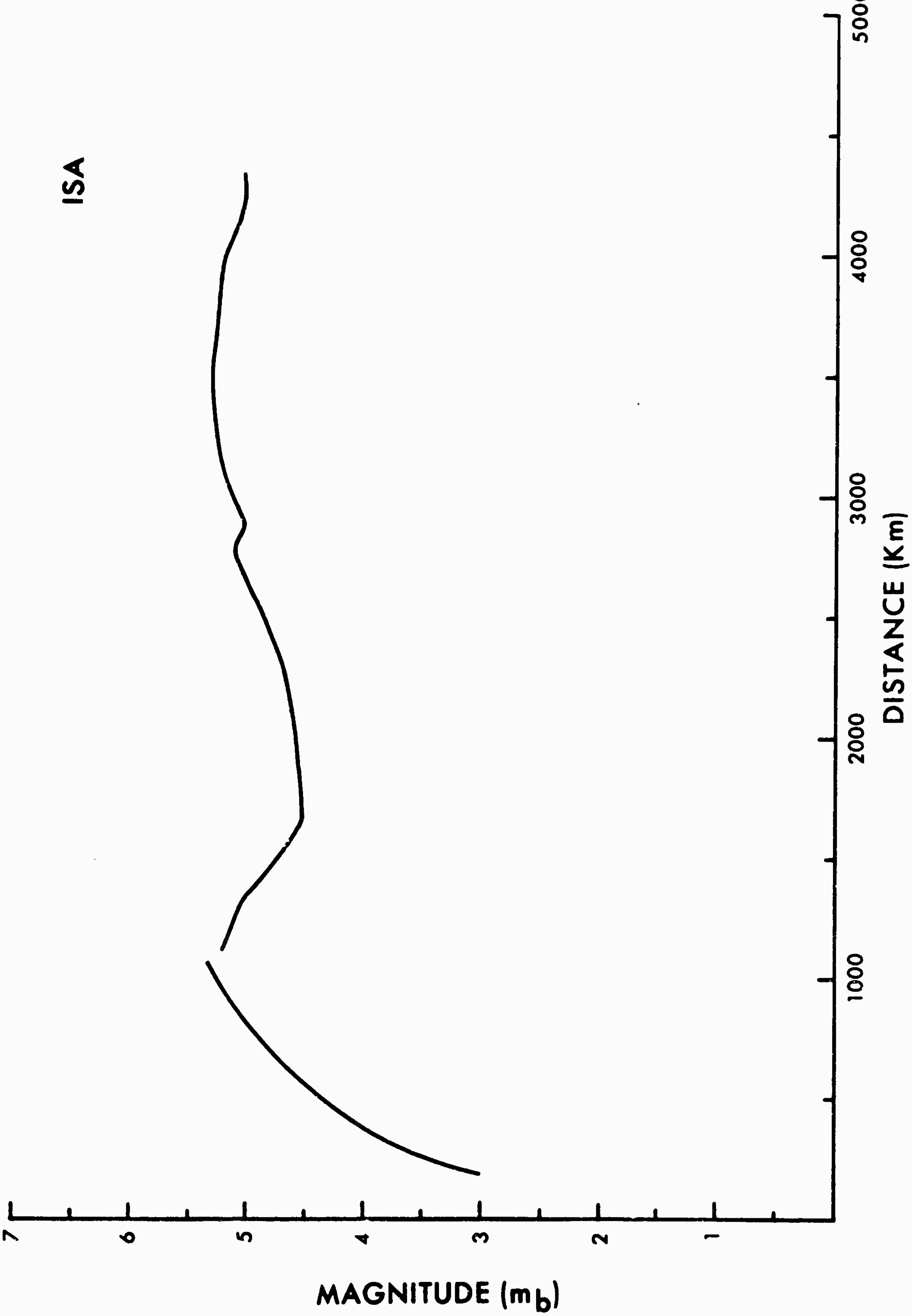
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DISTANCE (Km)
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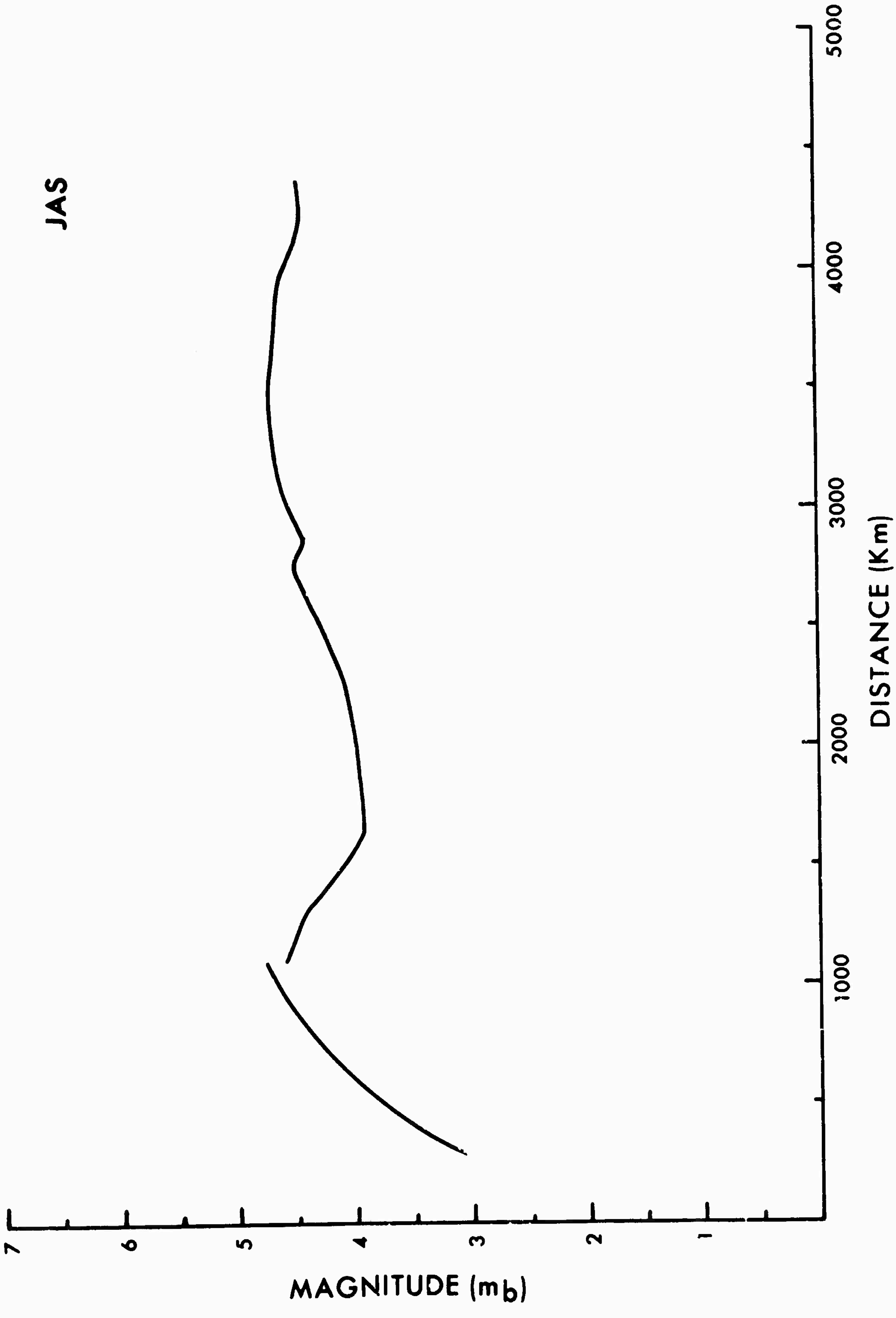
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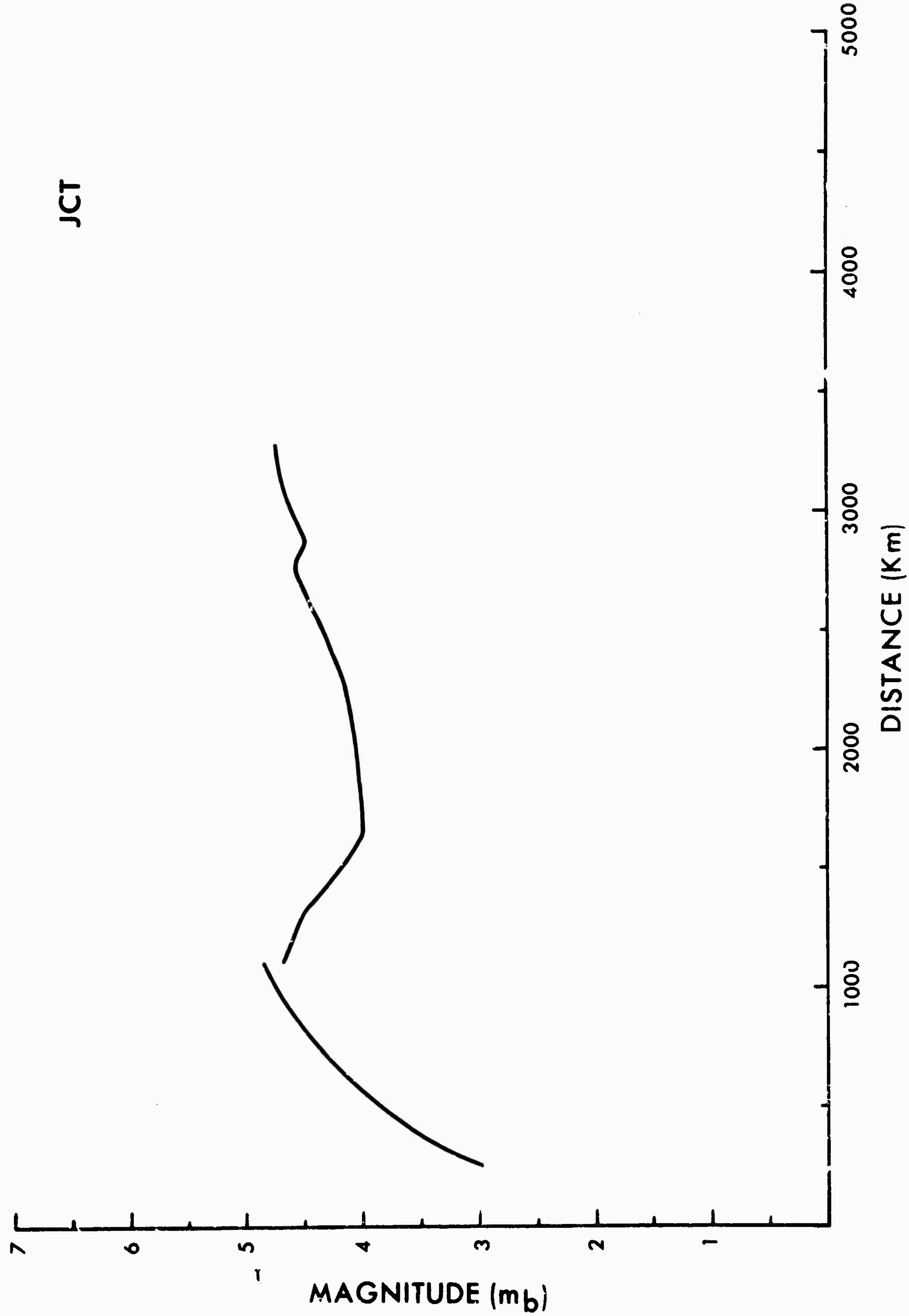
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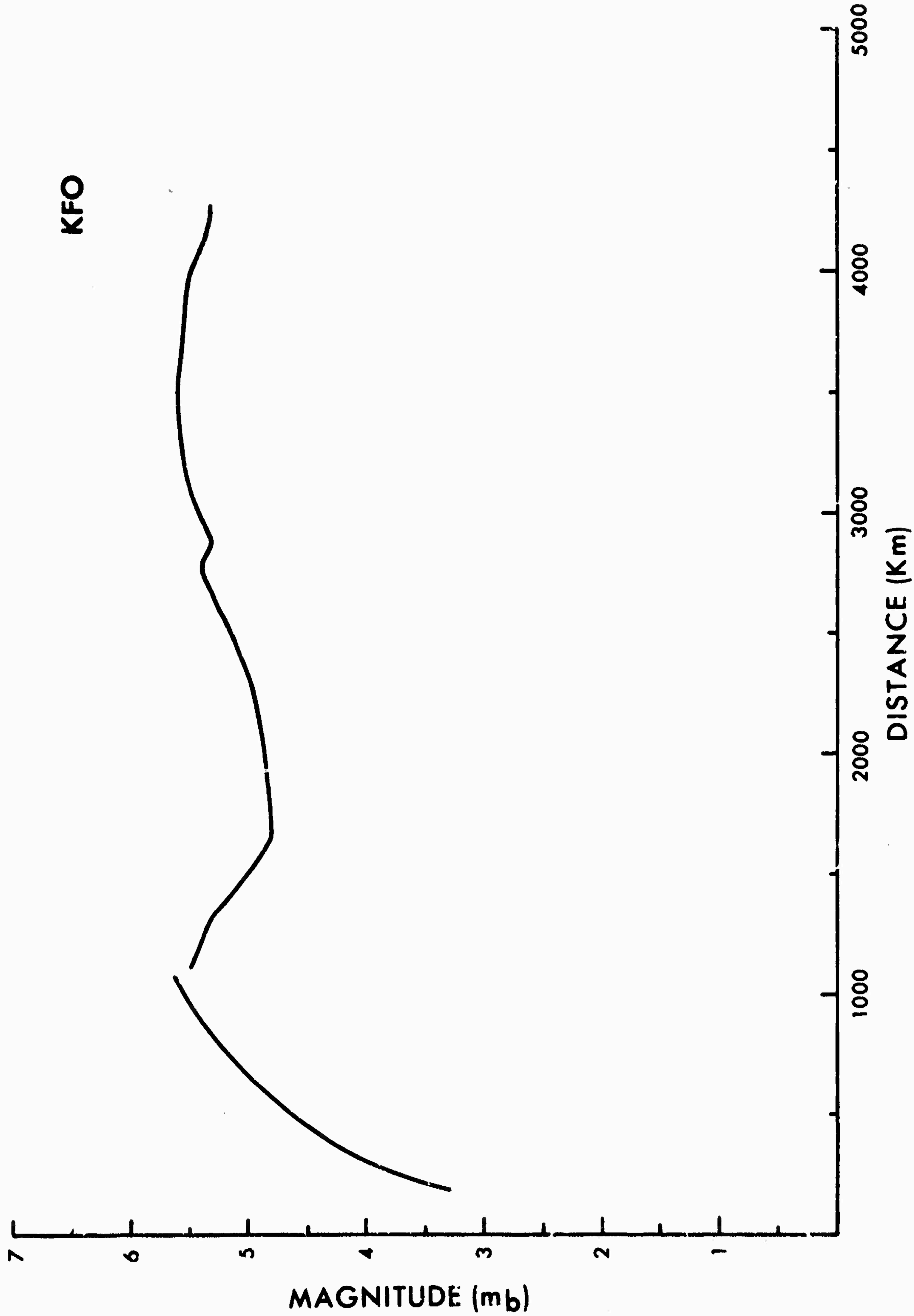
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DISTANCE (Km)
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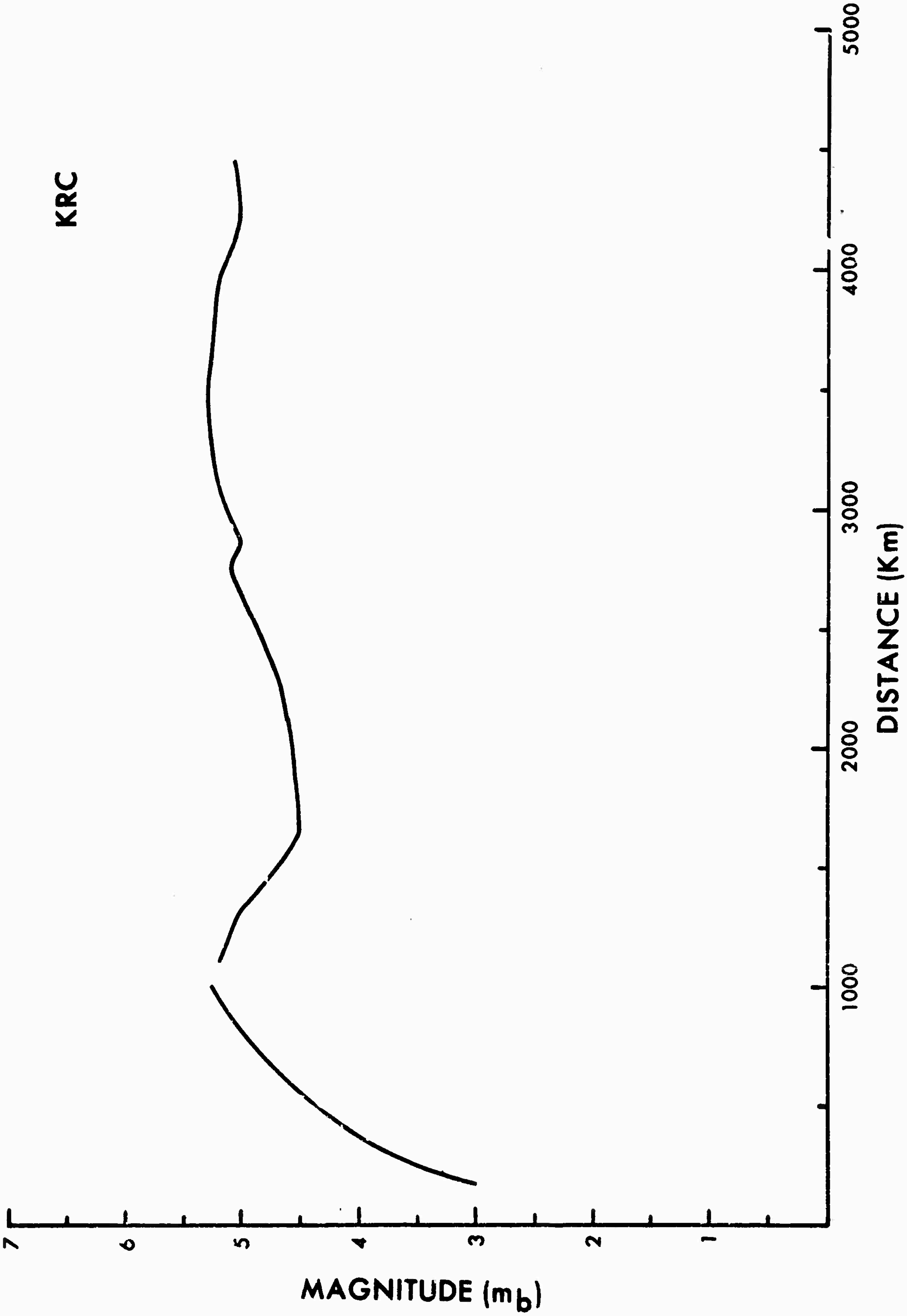

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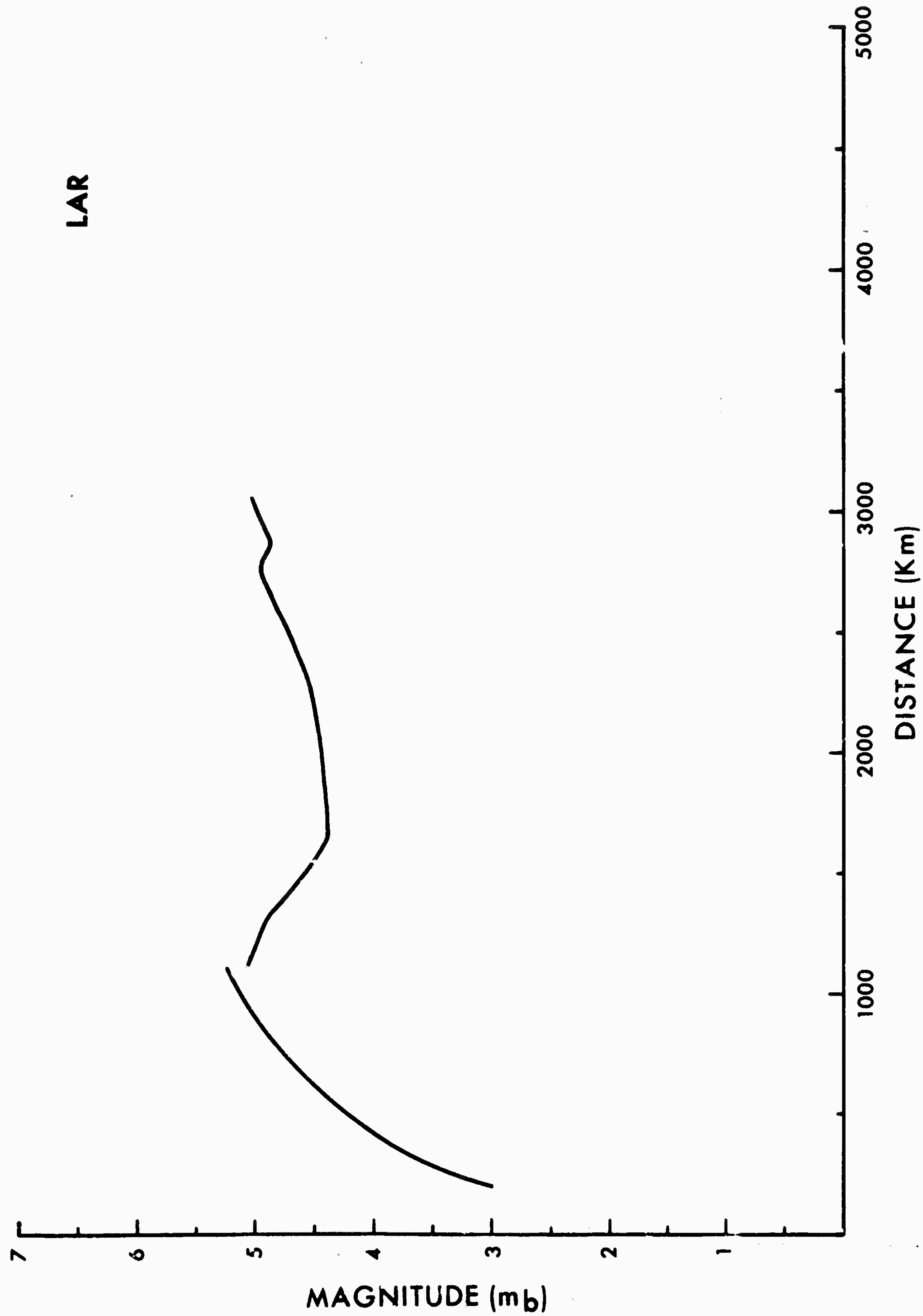
DISTANCE (Km)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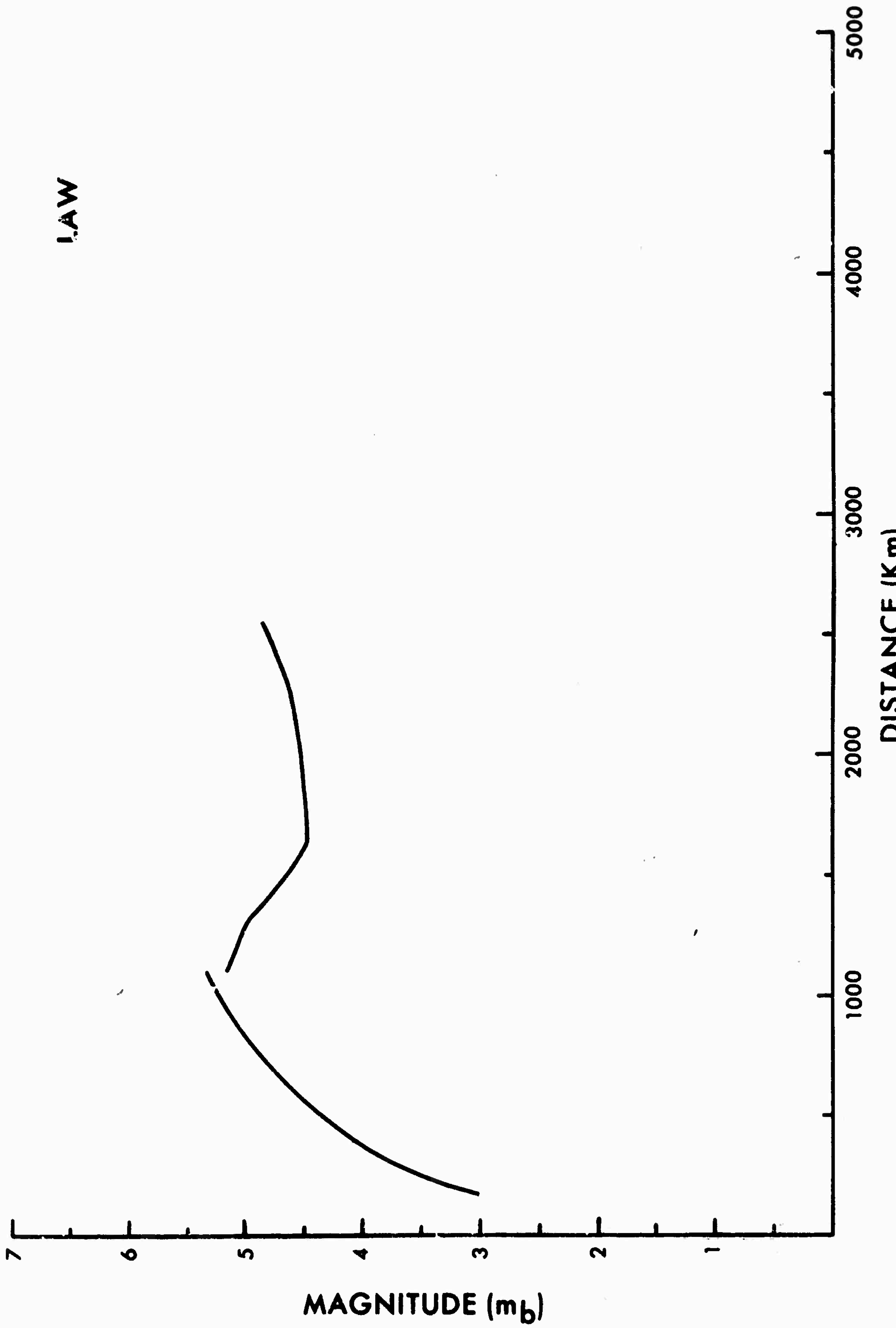
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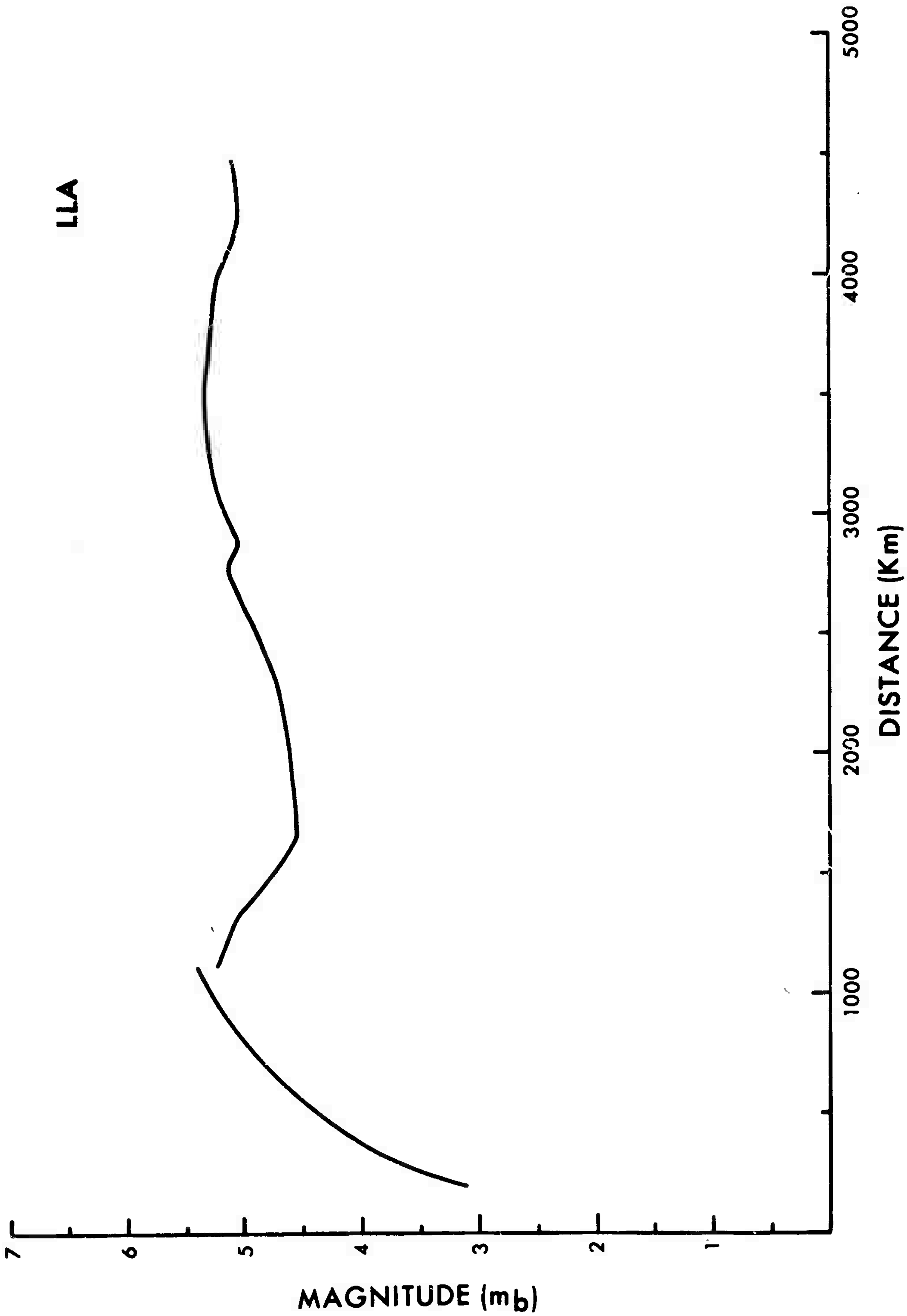
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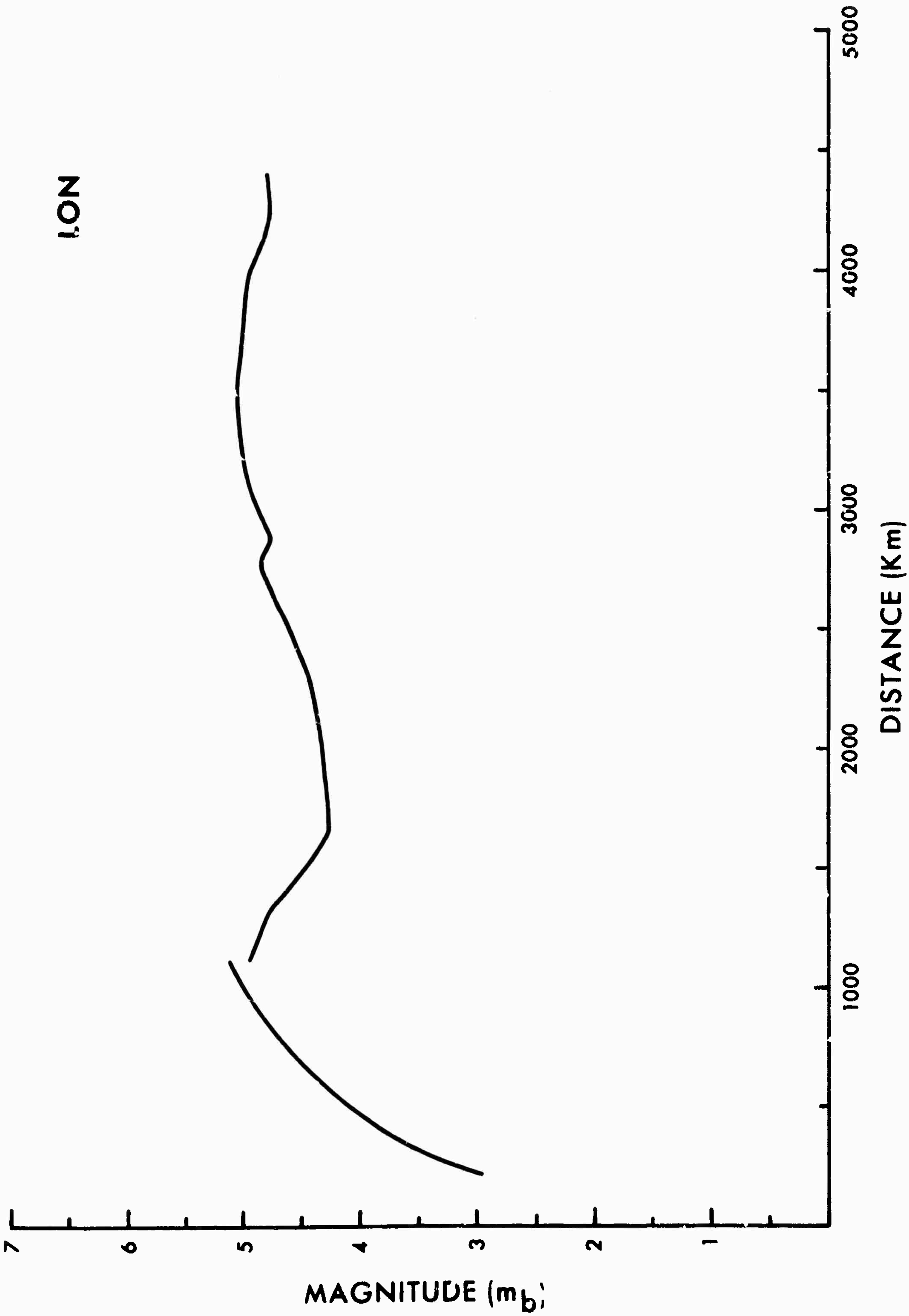
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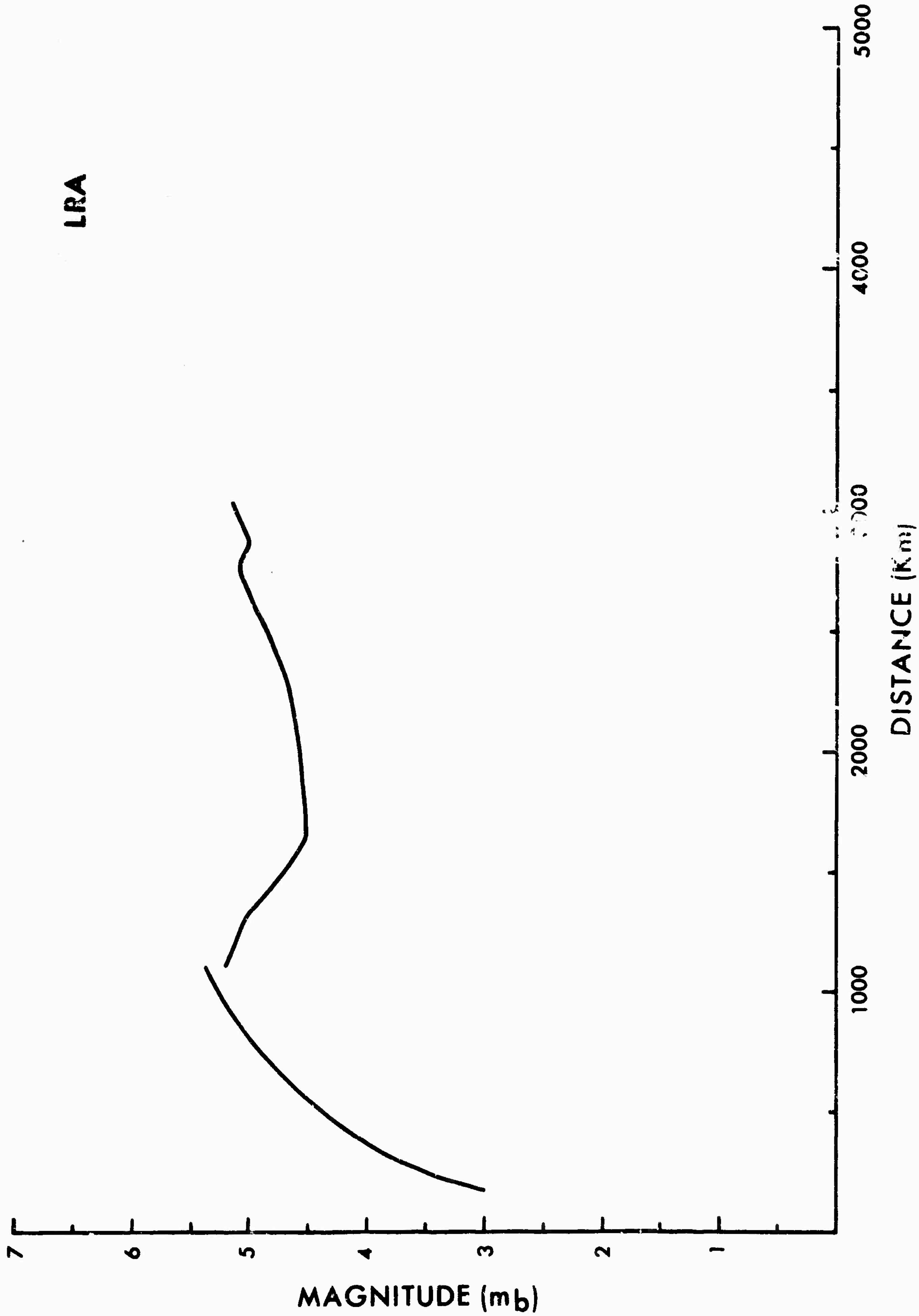
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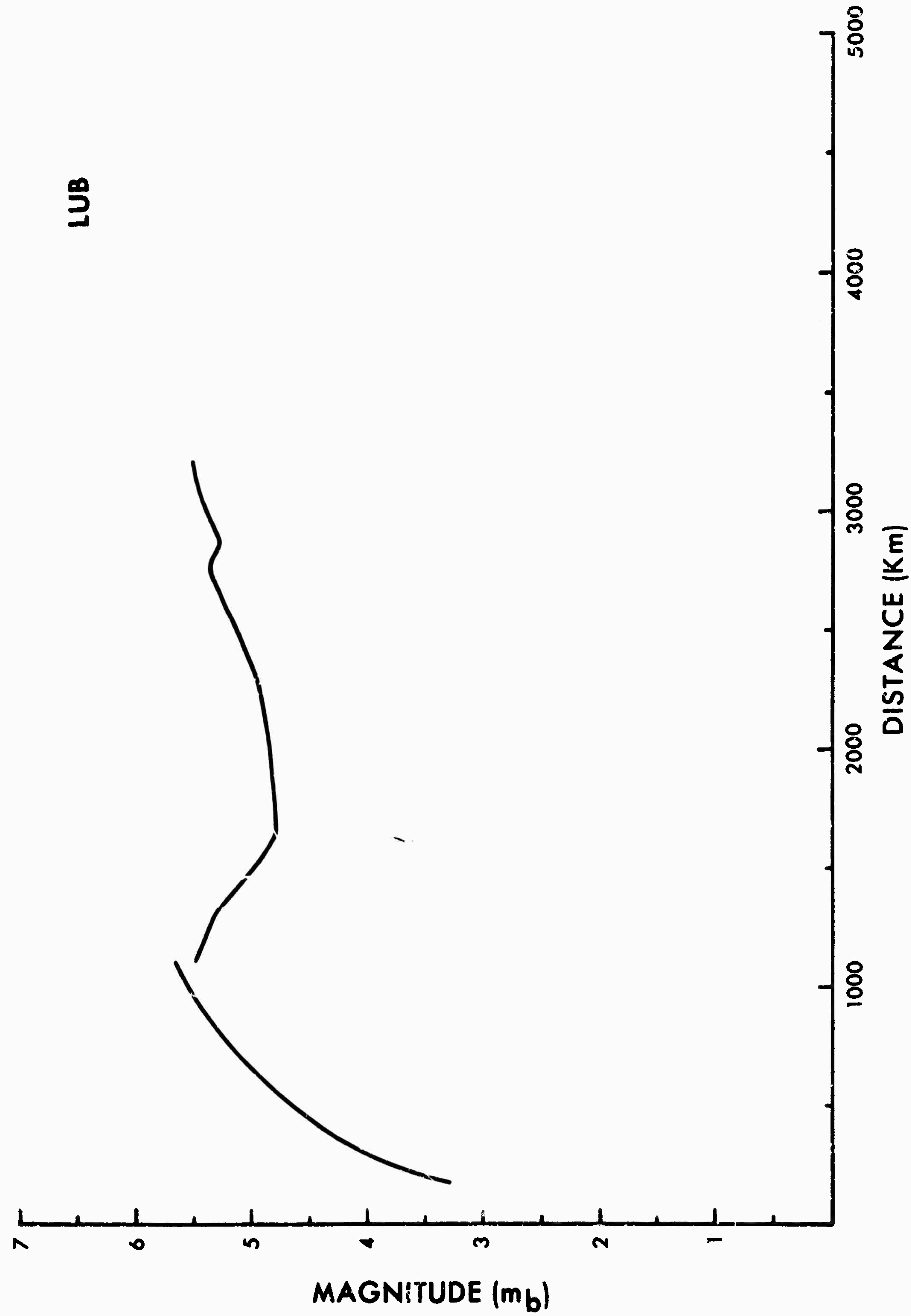

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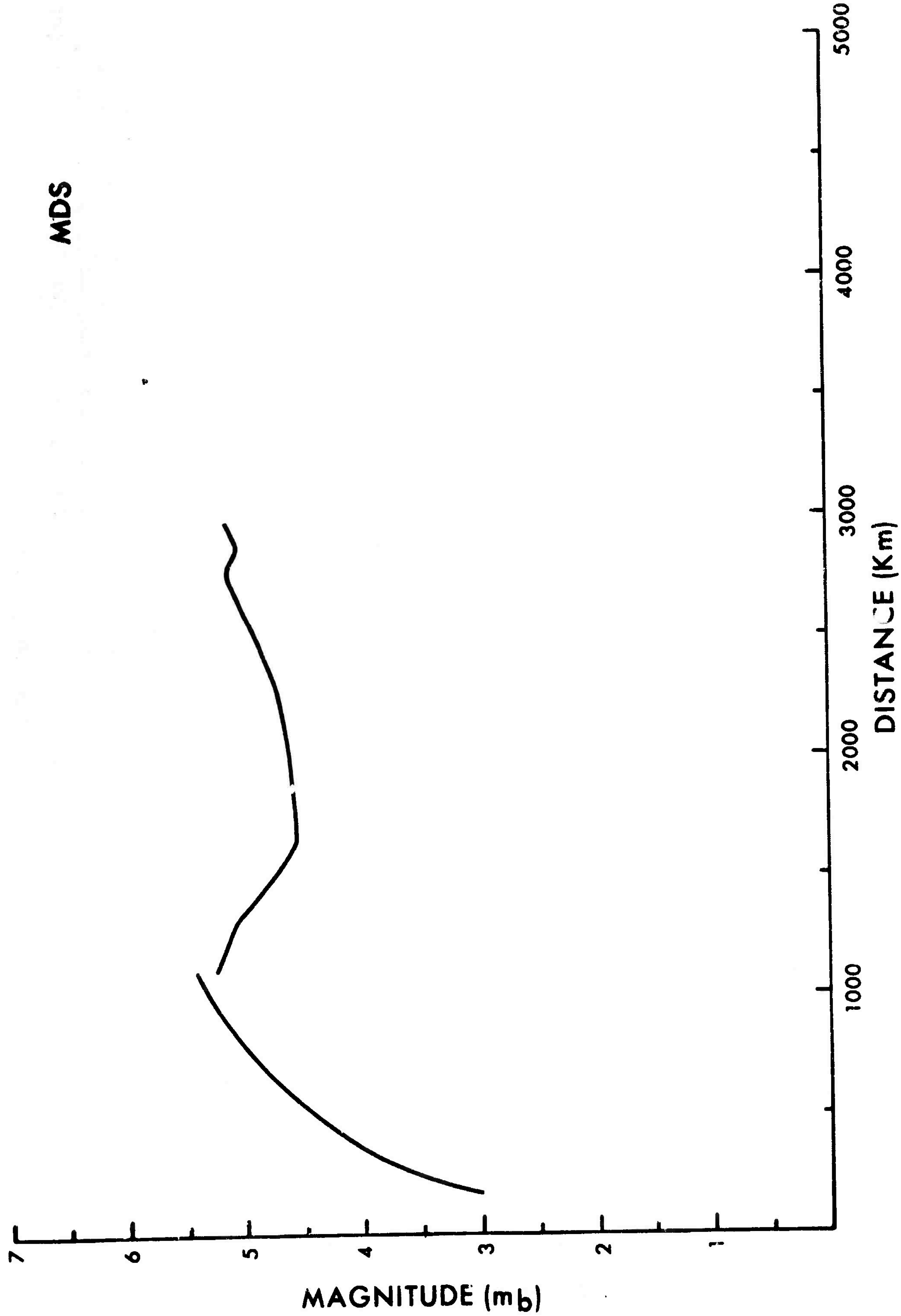
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MAGNITUDE (mb)
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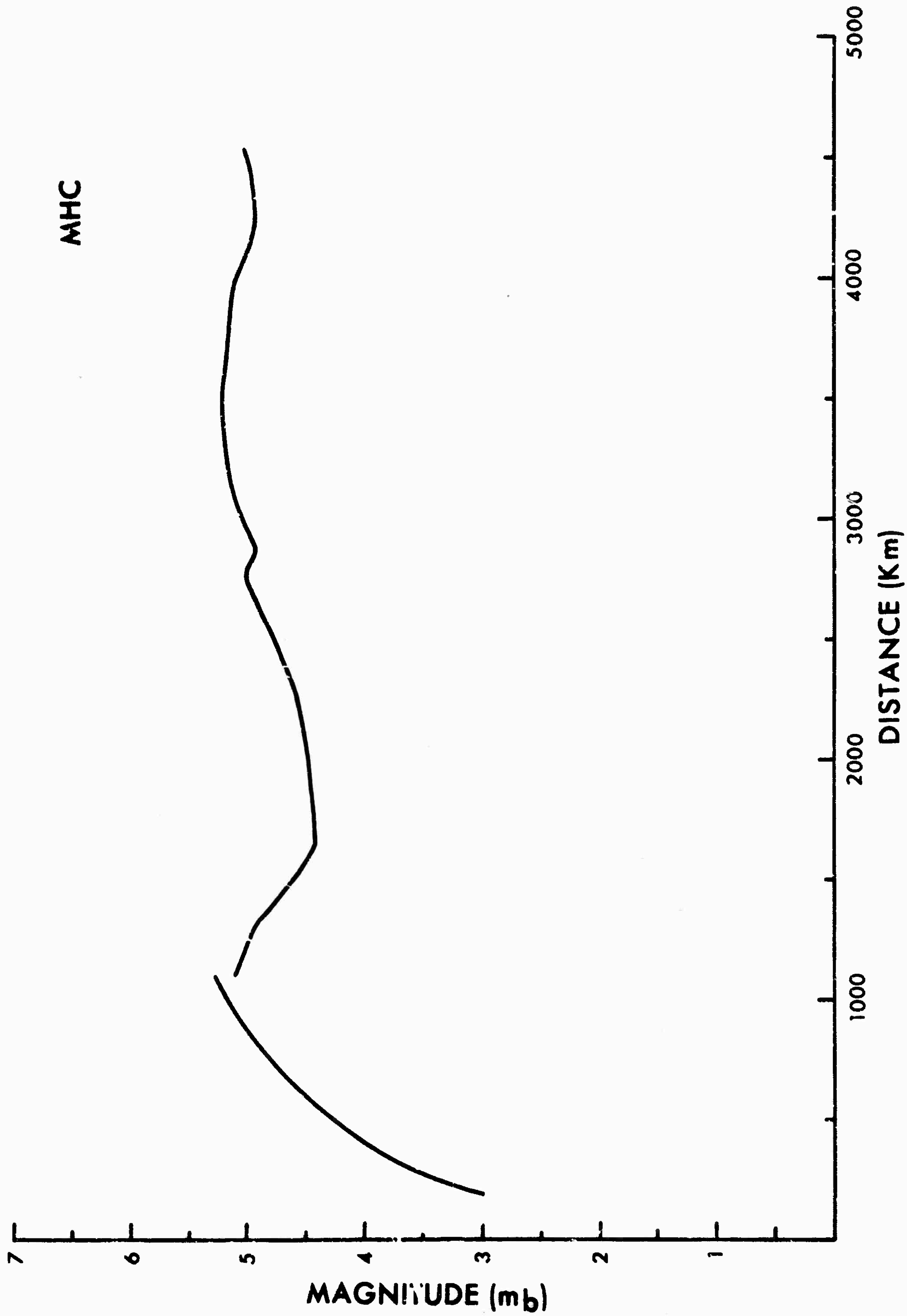
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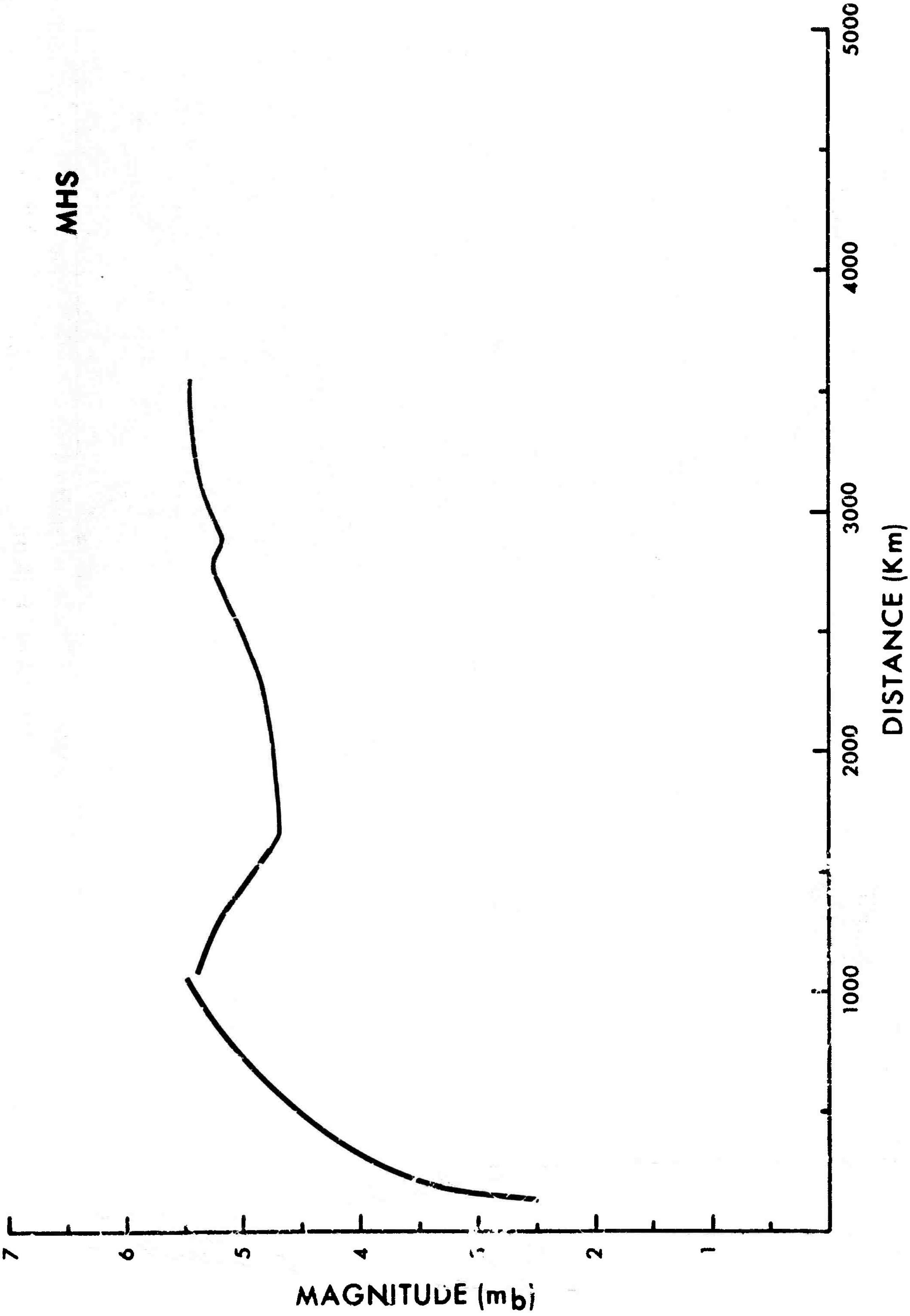
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MAGNITUDE (mb)
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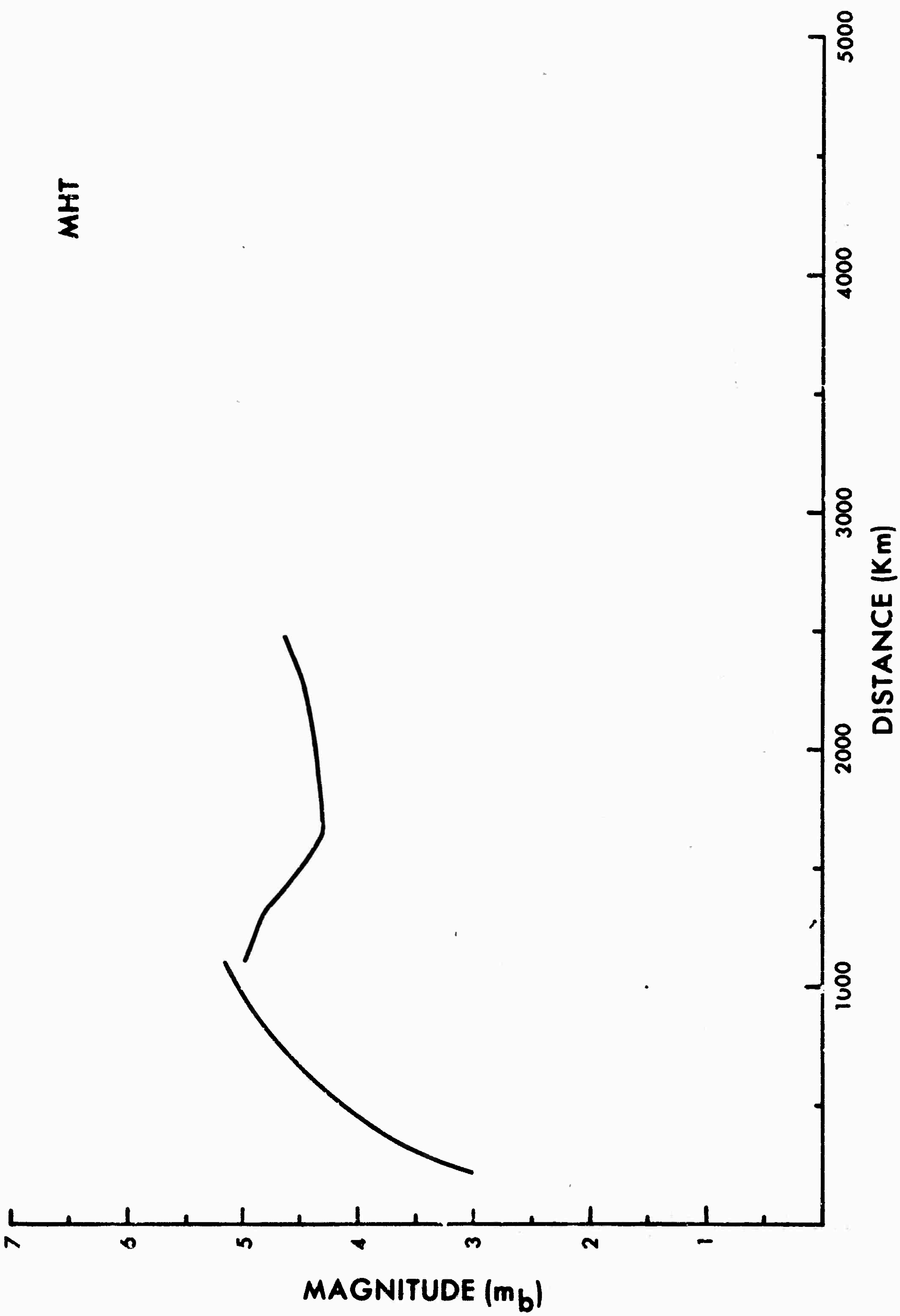
DISTANCE (Km)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MAGNITUDE (m_b)
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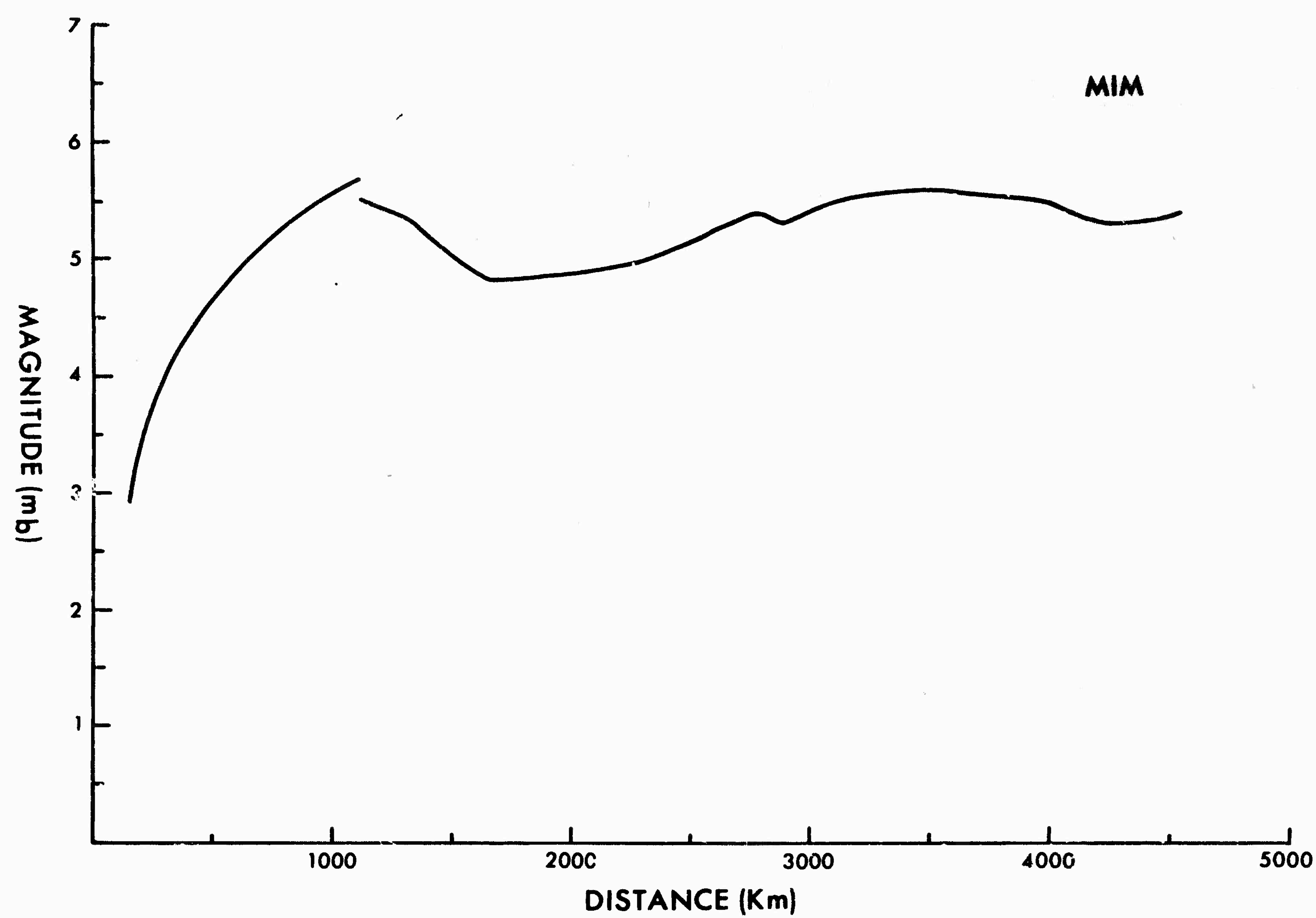
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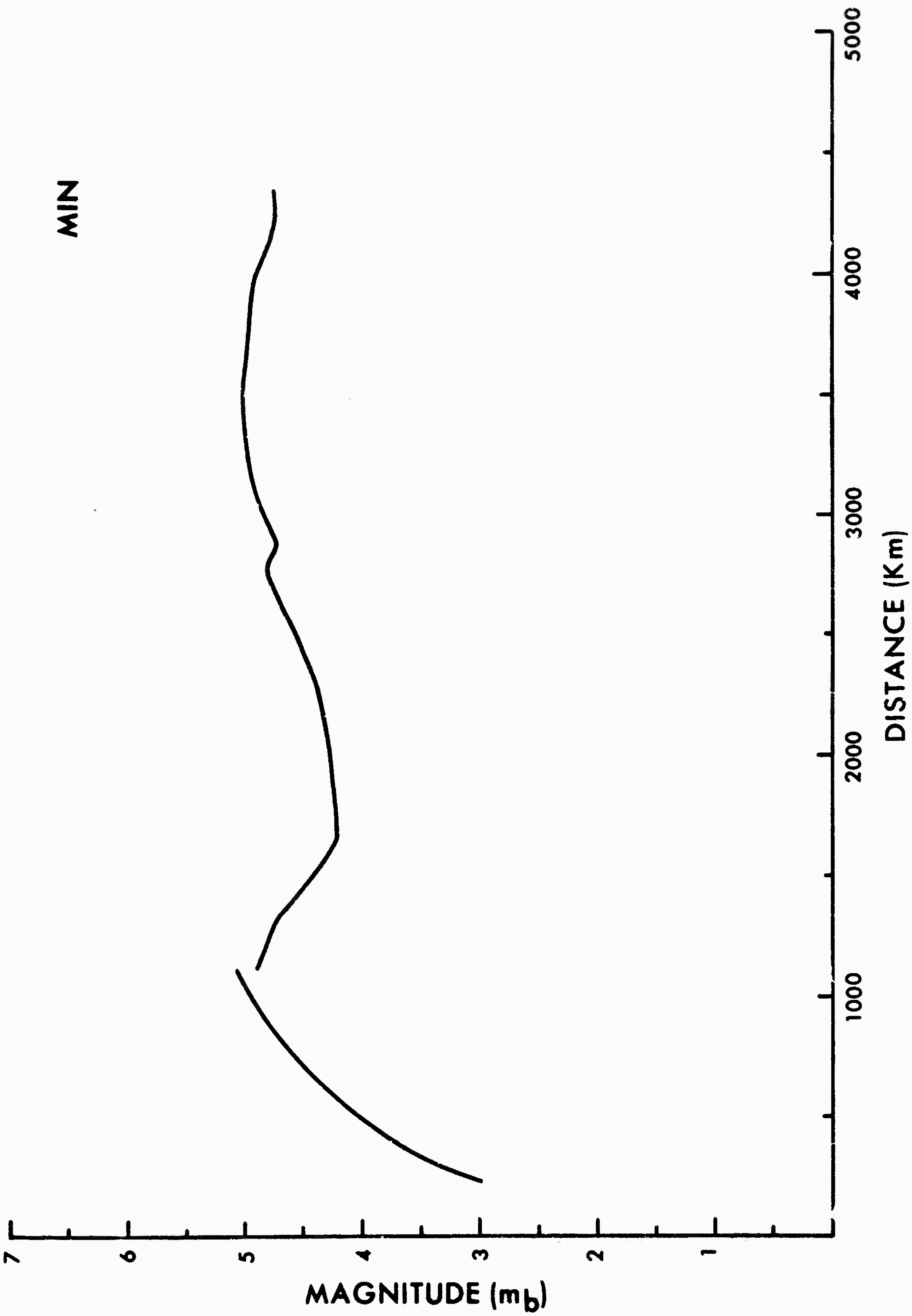
DISTANCE (Km)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MAGNITUDE (m_b)
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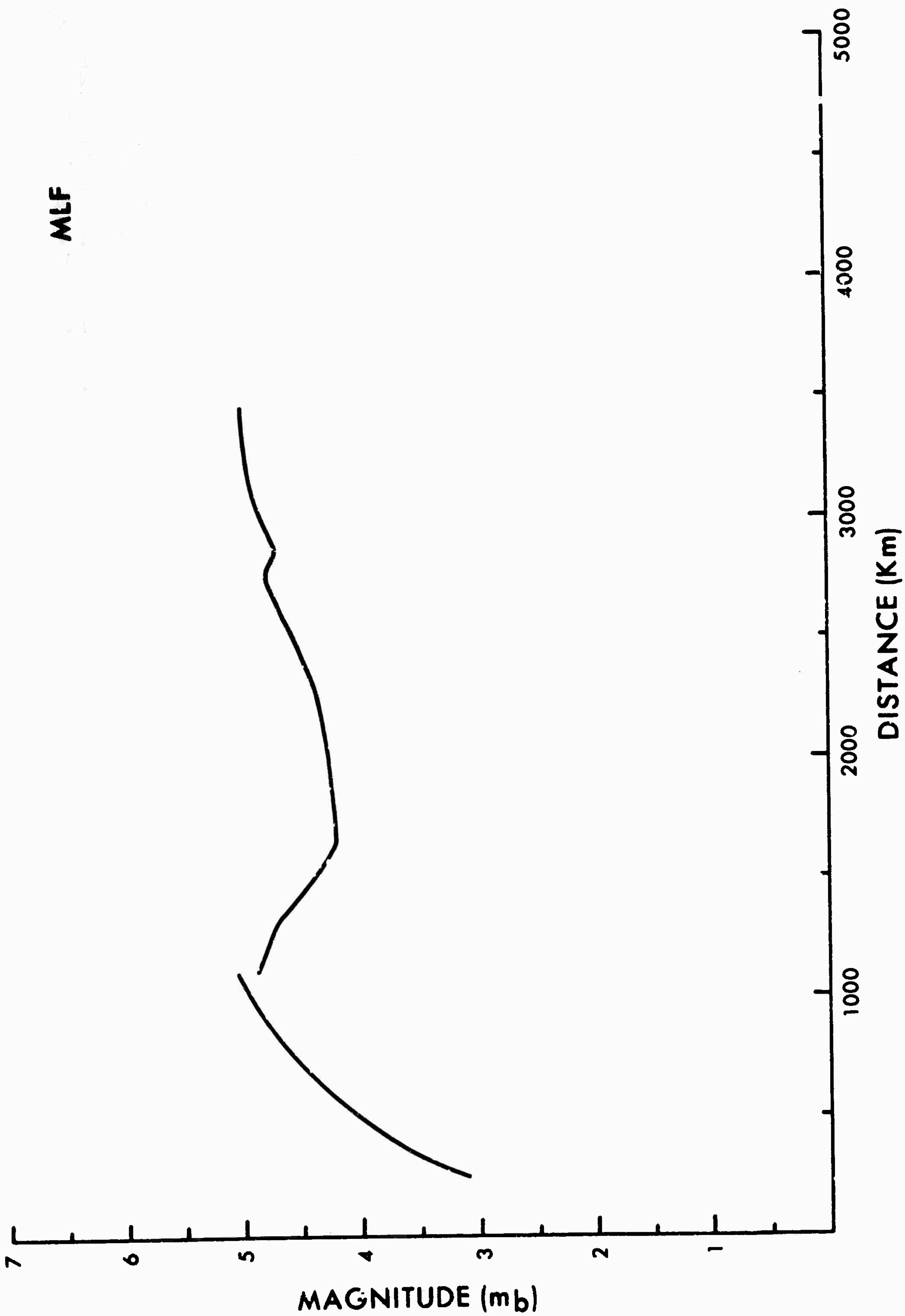
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DISTANCE (Km)
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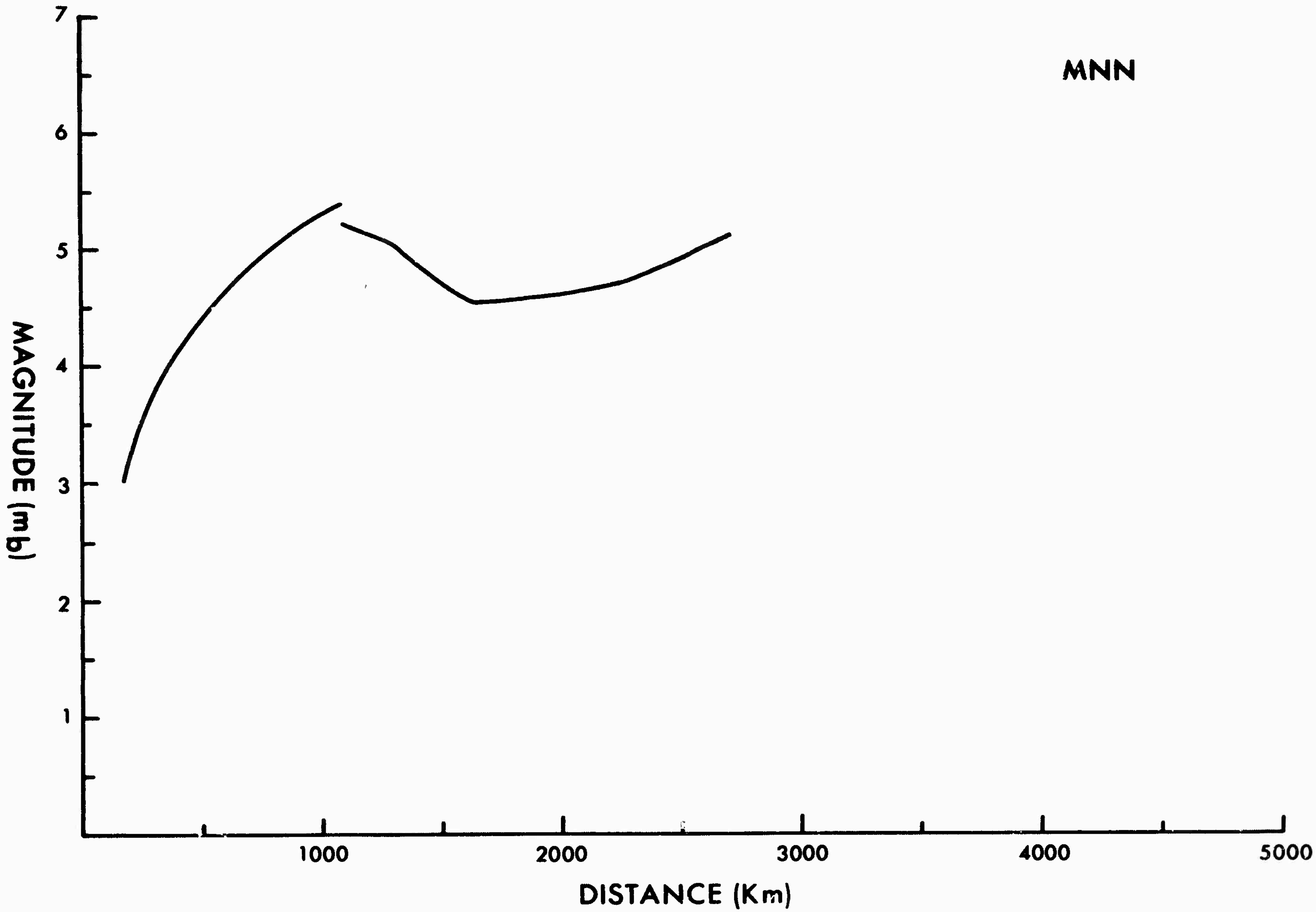
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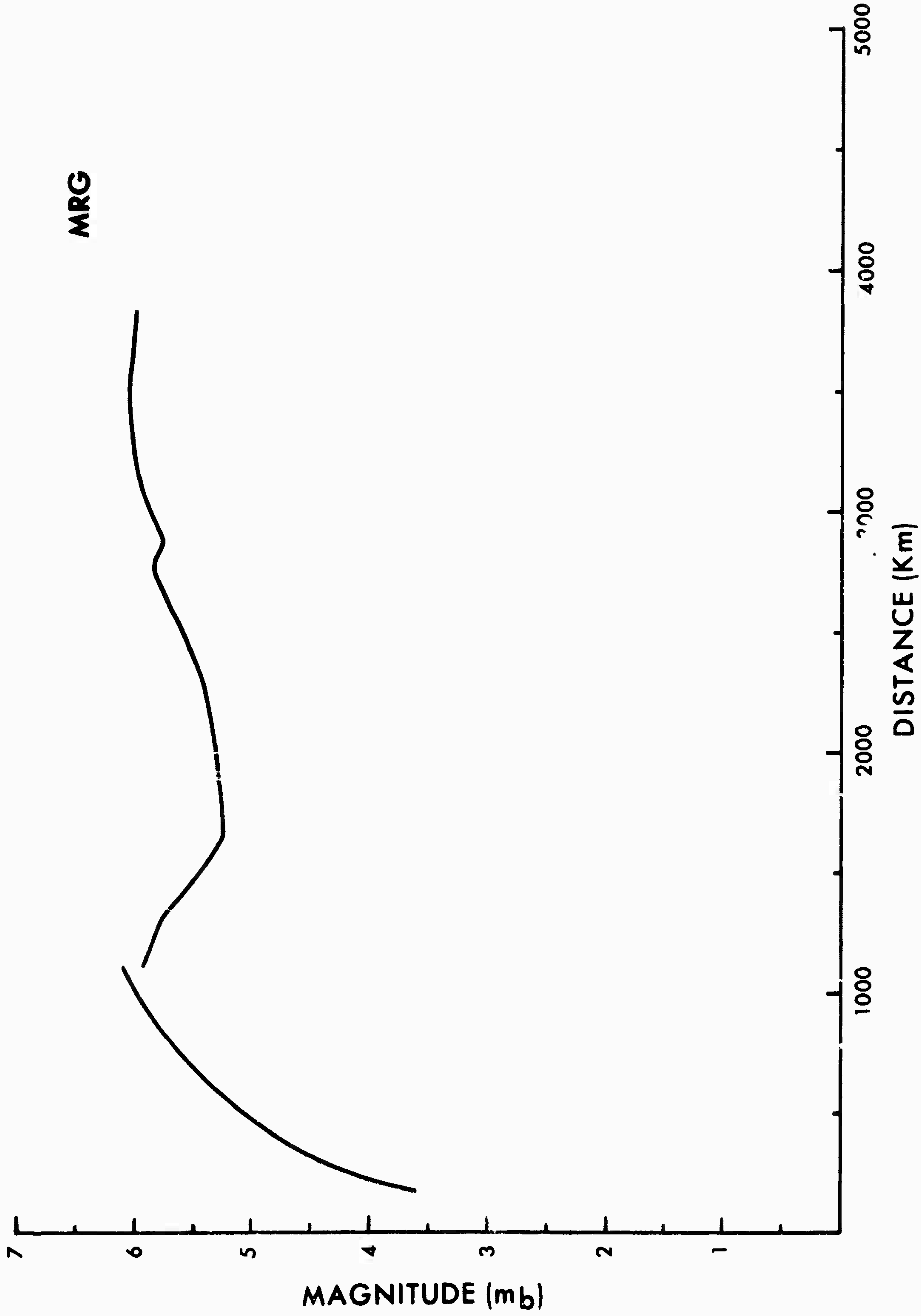
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DISTANCE (Km)
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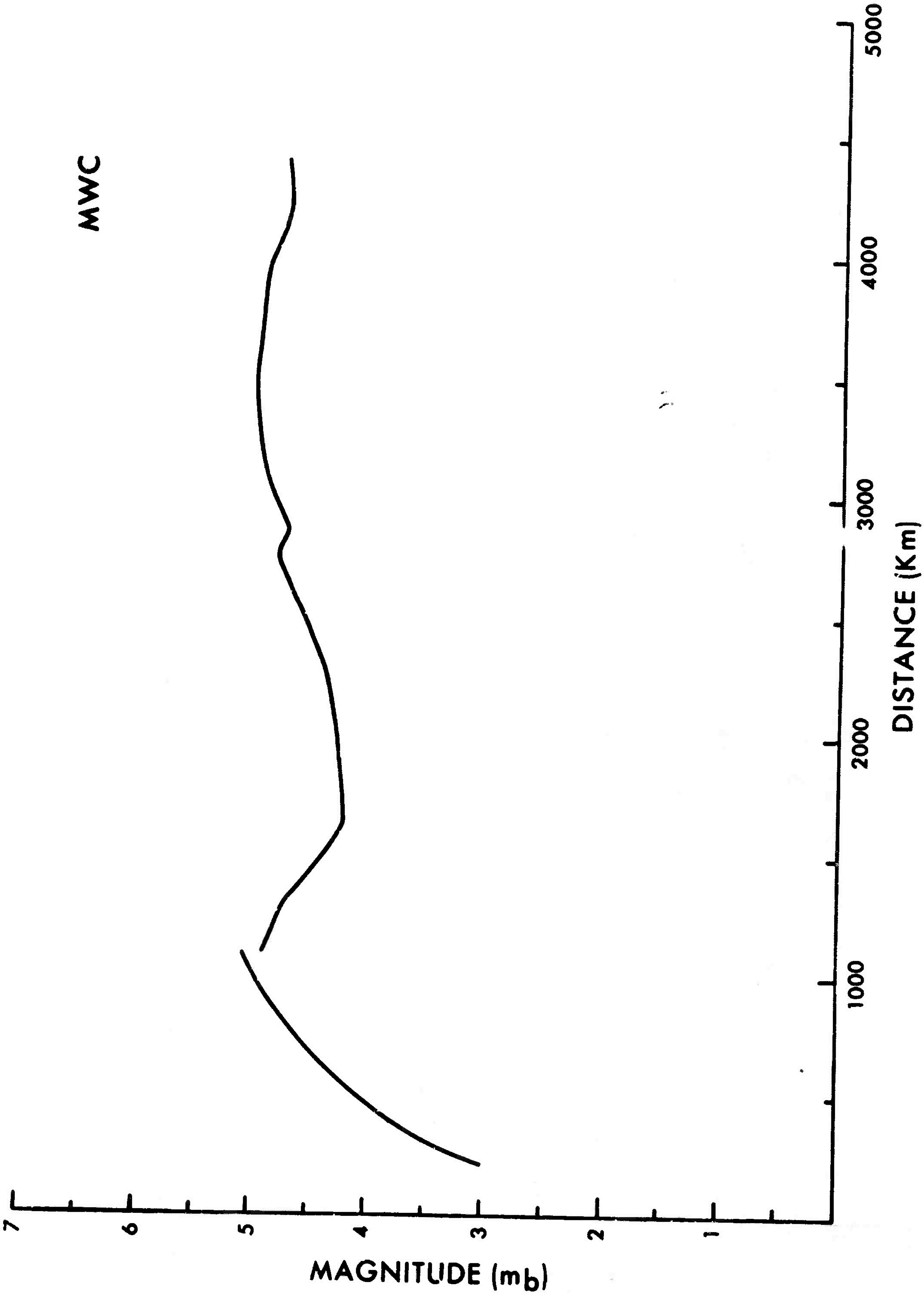
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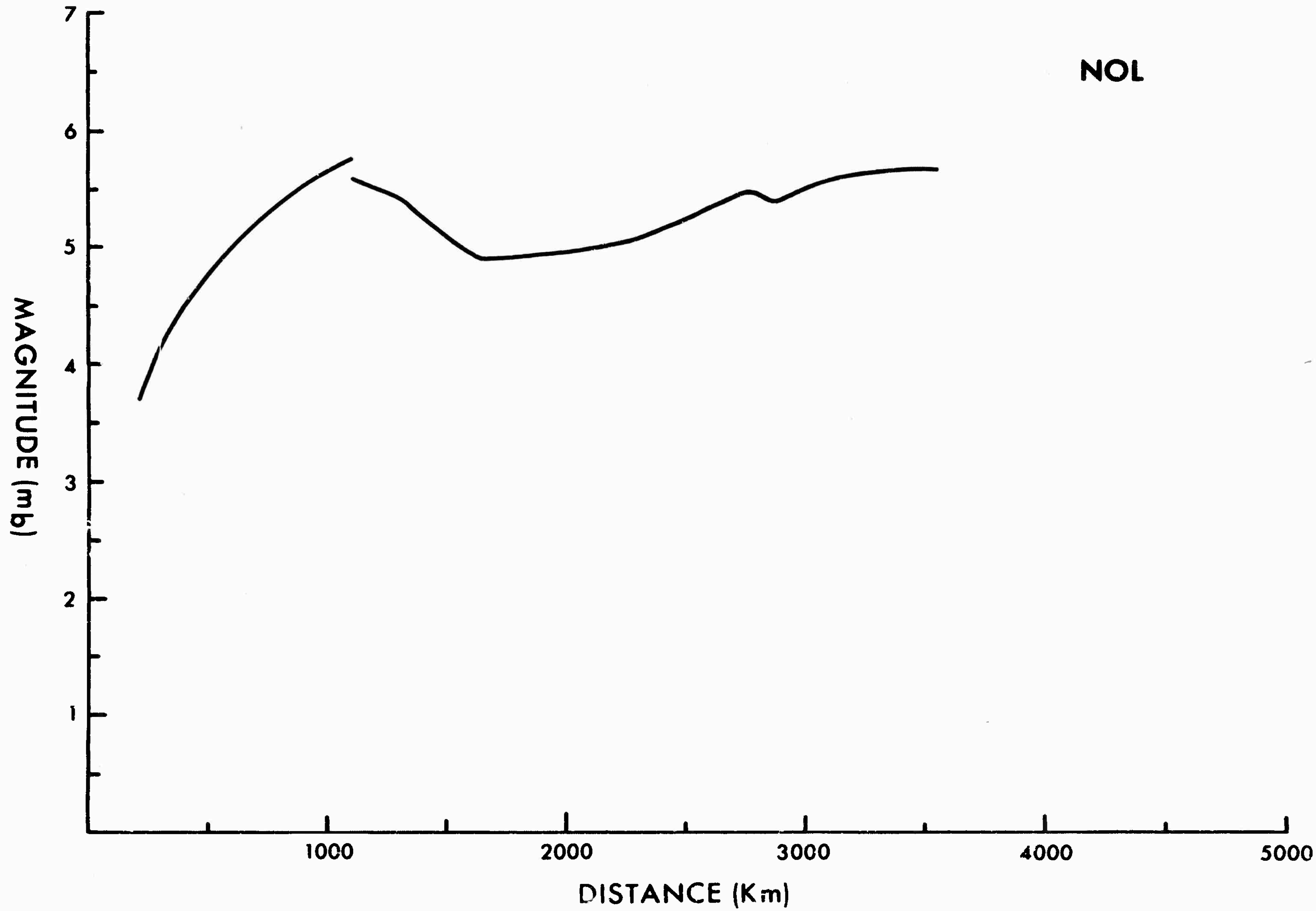
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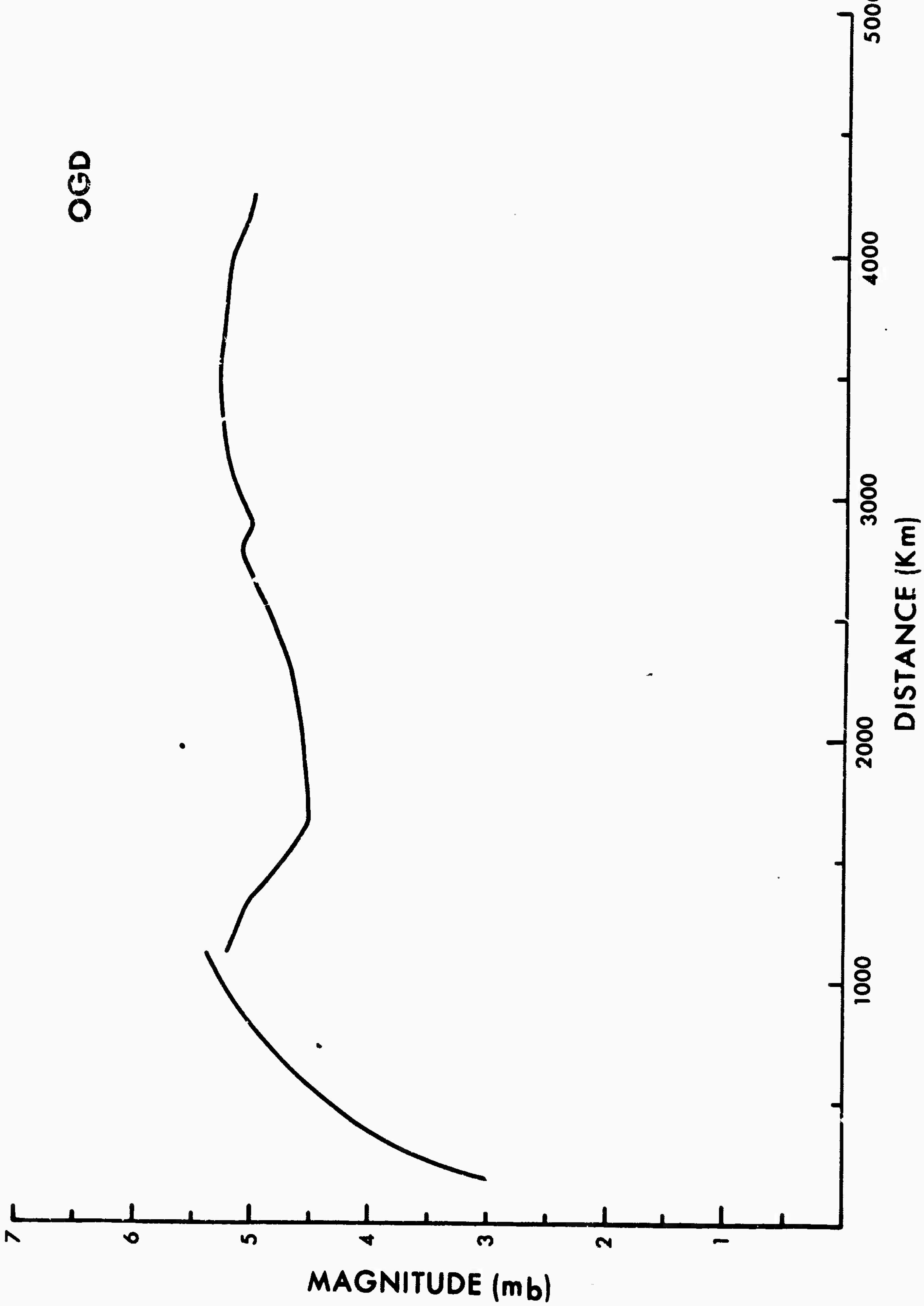
DISTANCE (Km)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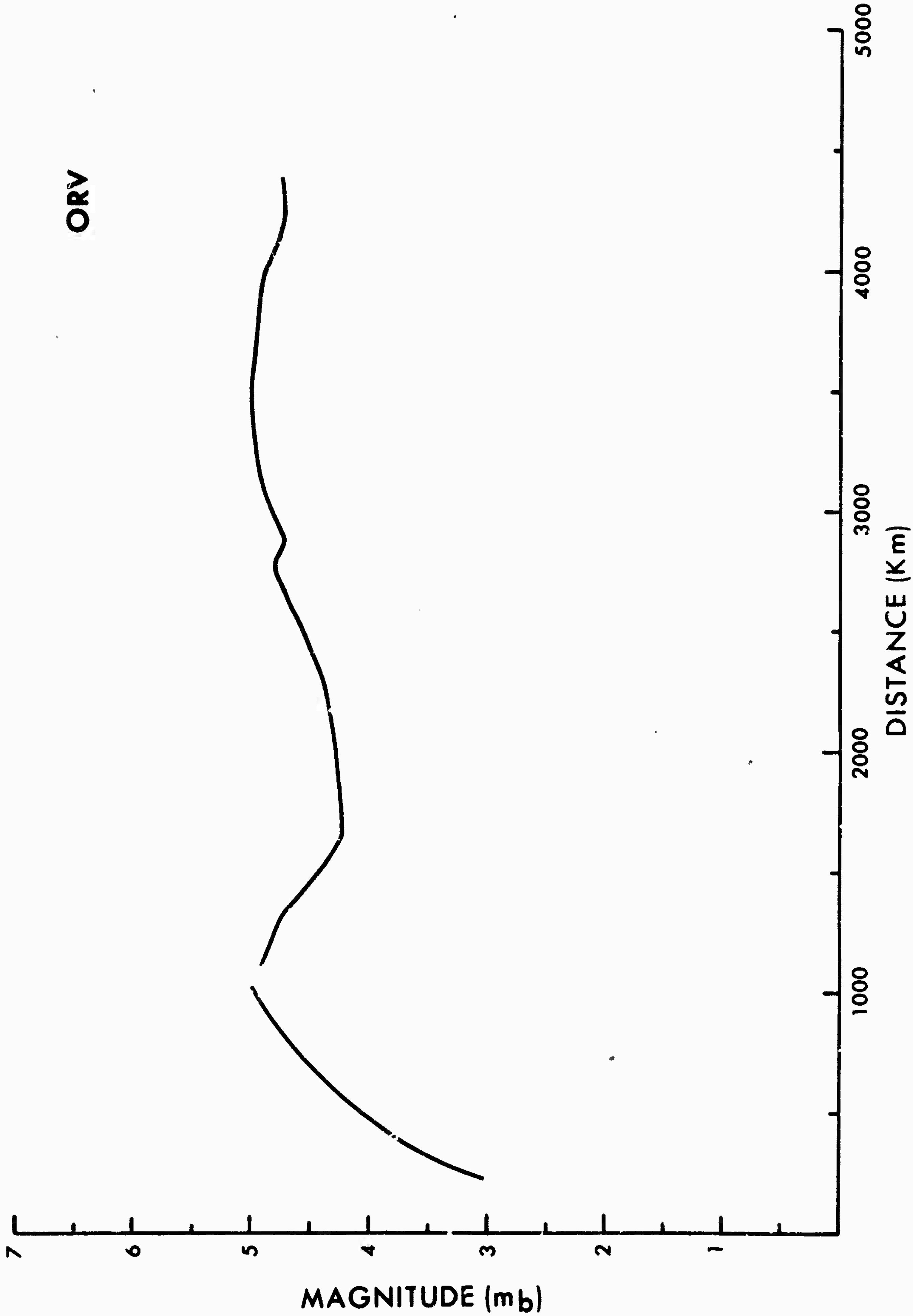
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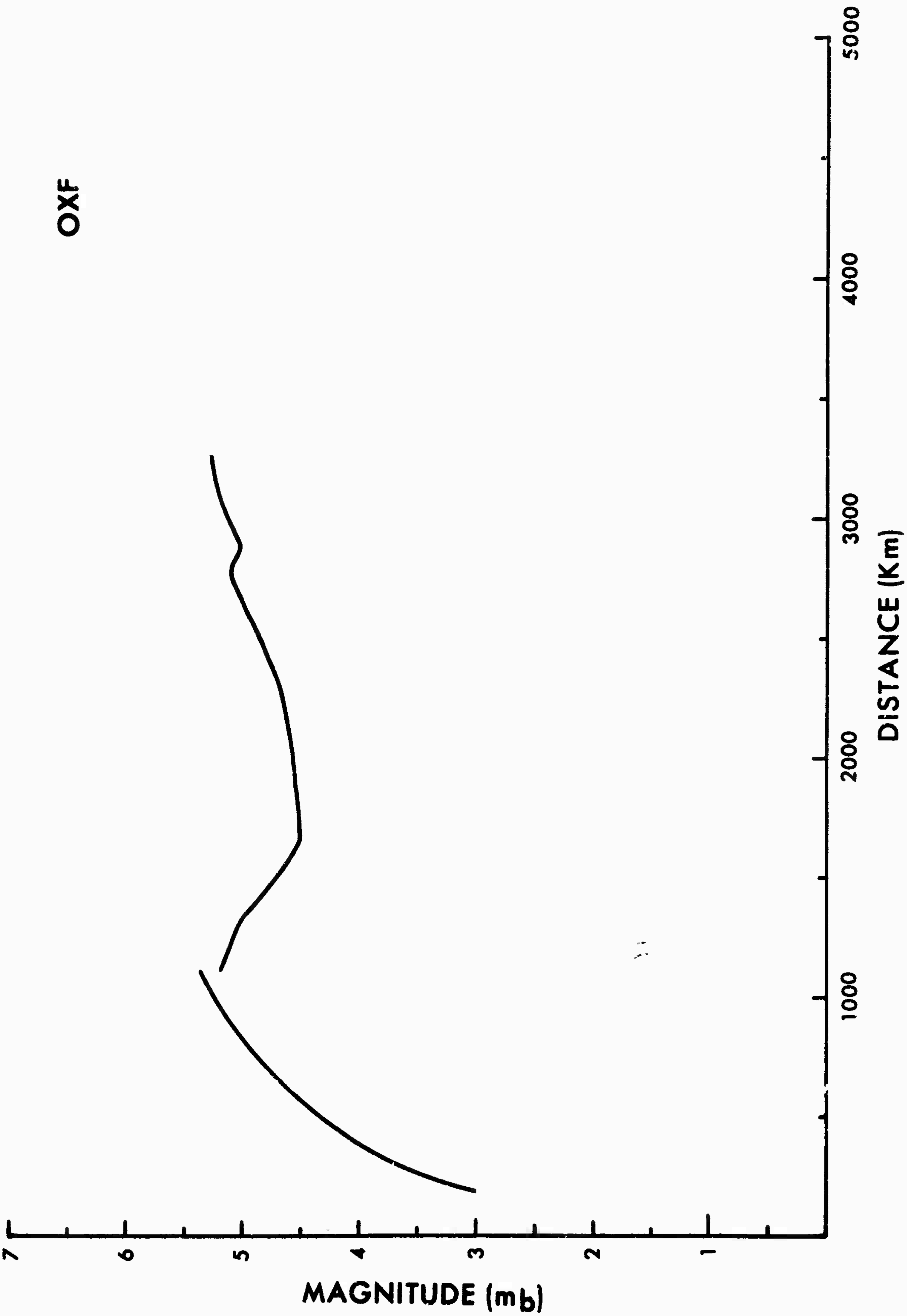
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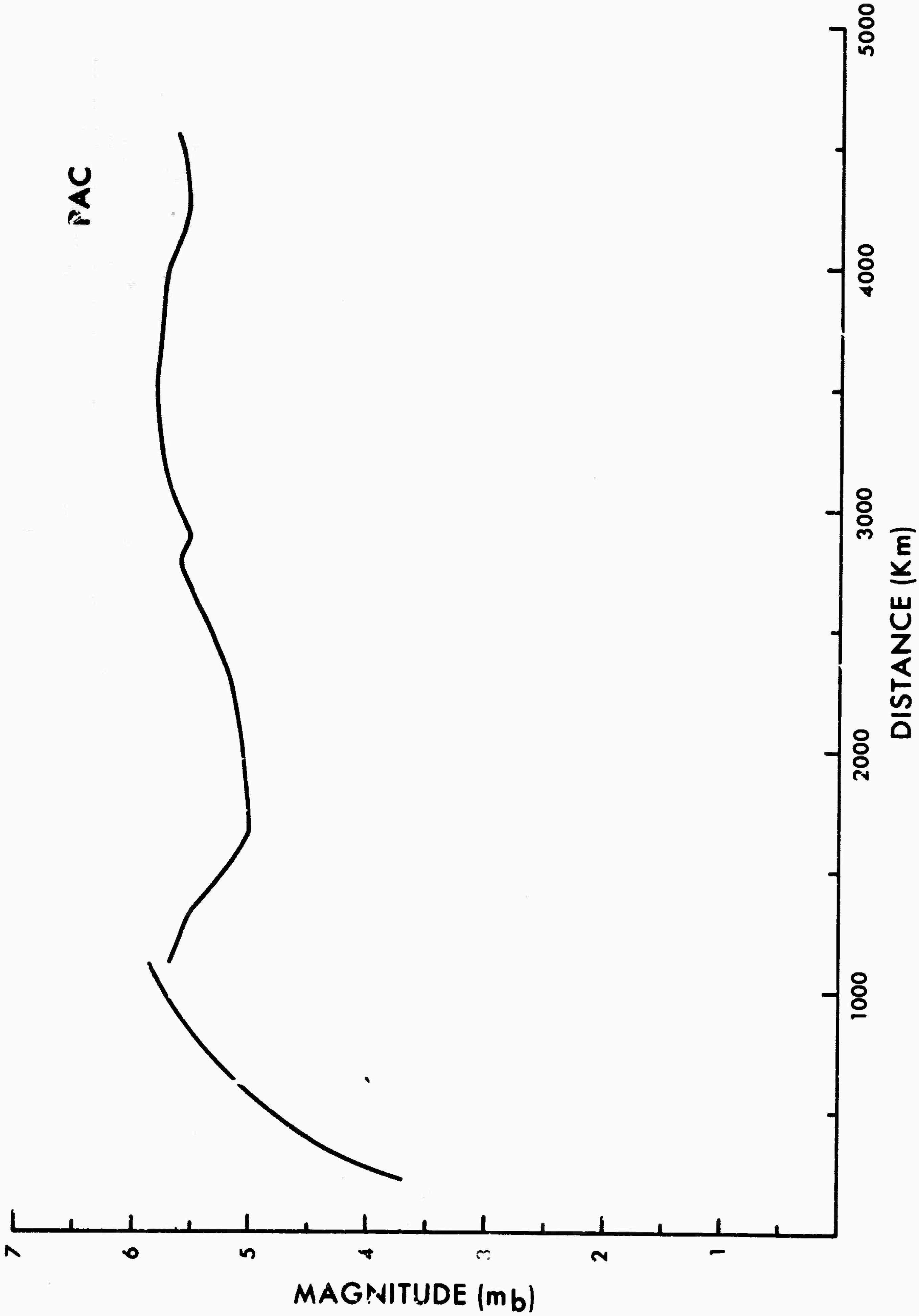
MAGNITUDE (mb)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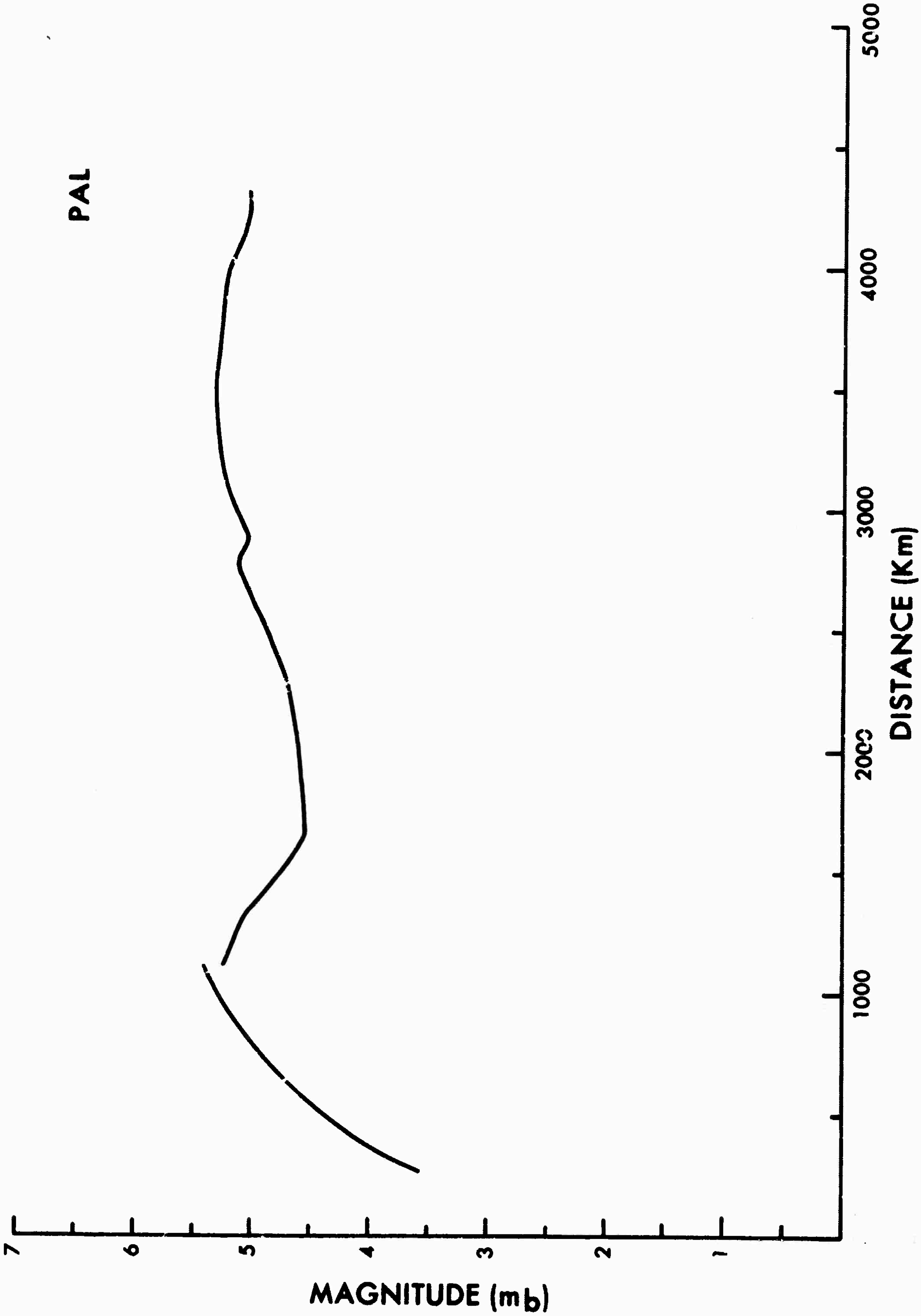
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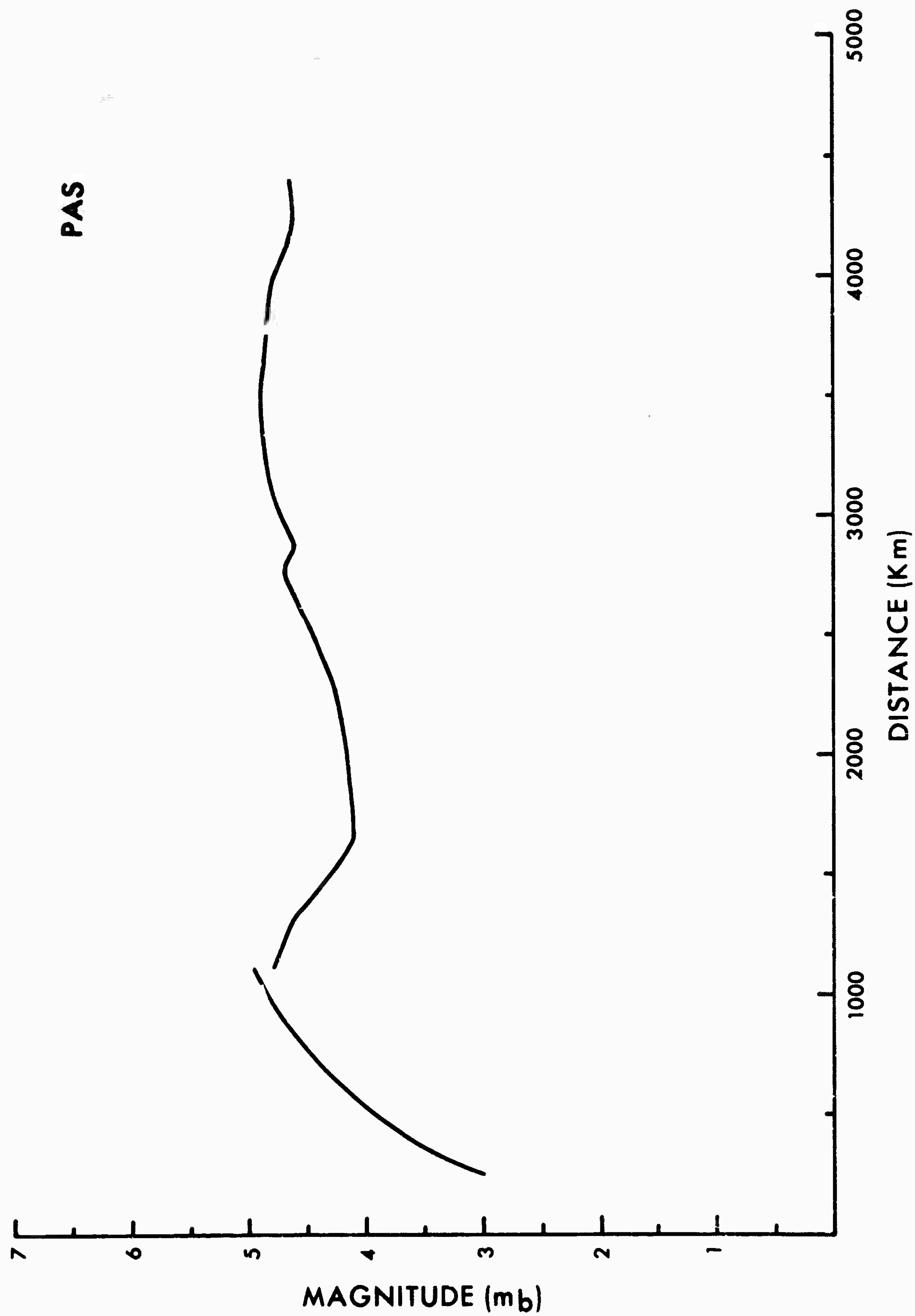

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DISTANCE (Km)
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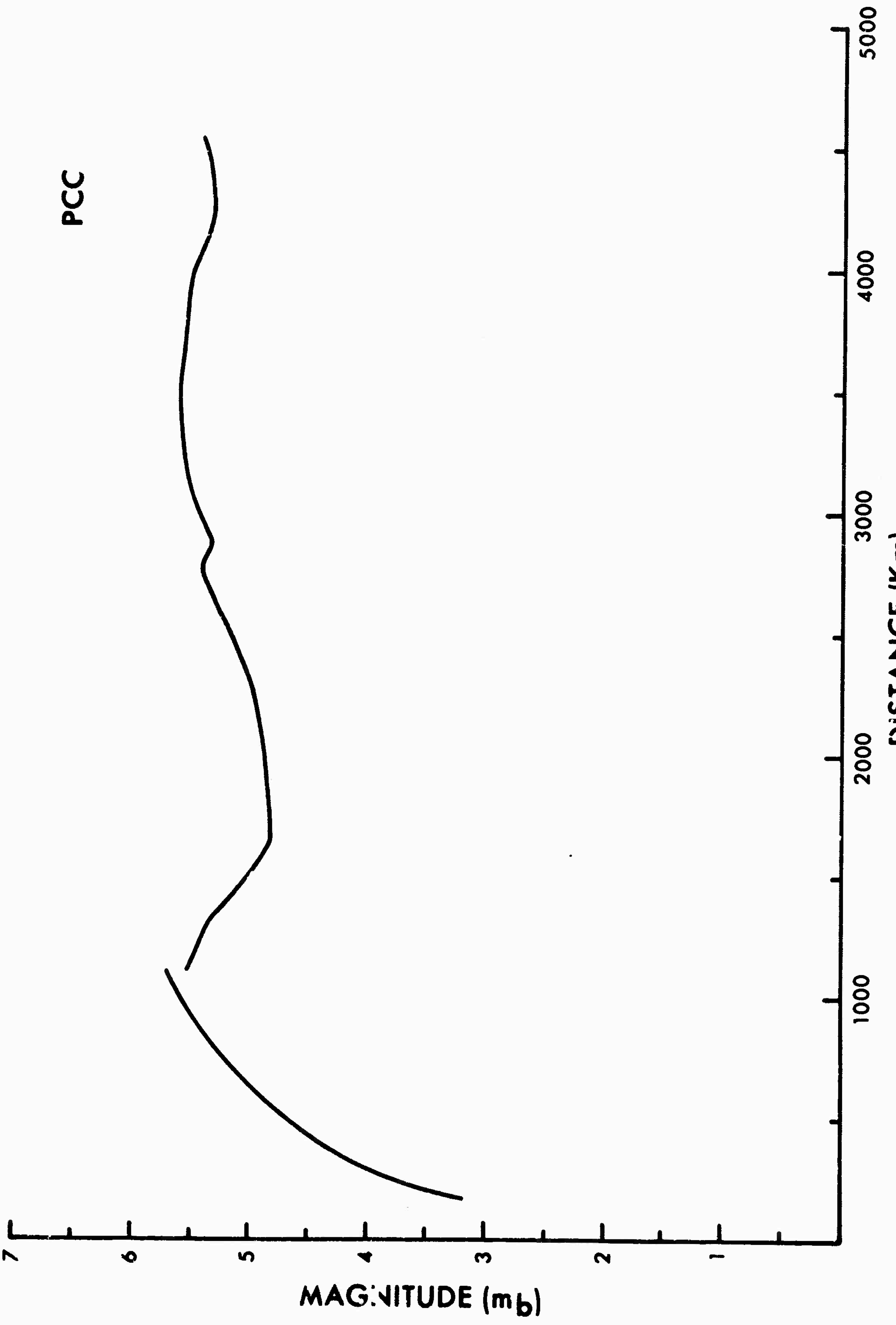

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MAGNITUDE (m_b)
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DISTANCE (Km)
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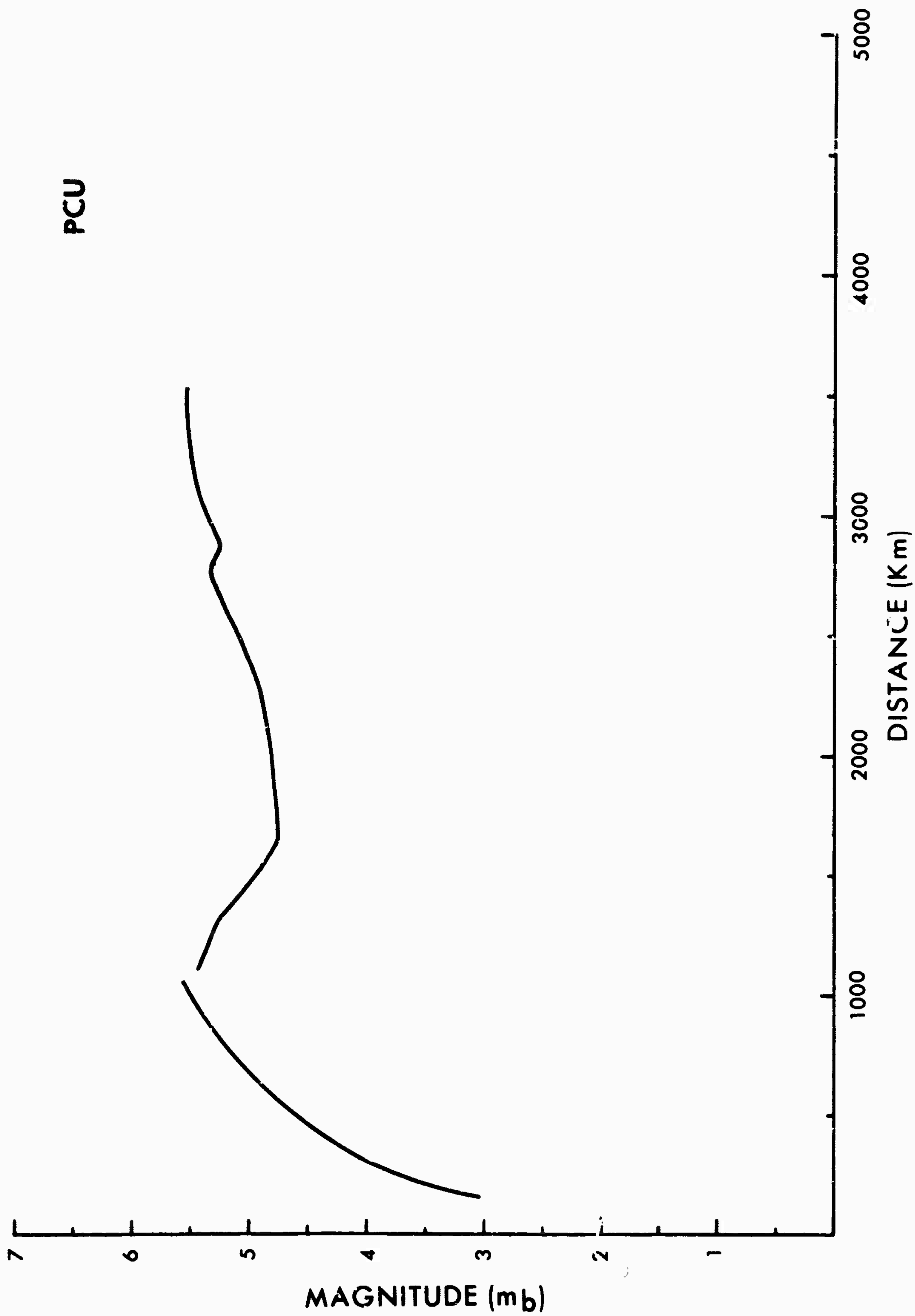

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DISTANCE (Km)
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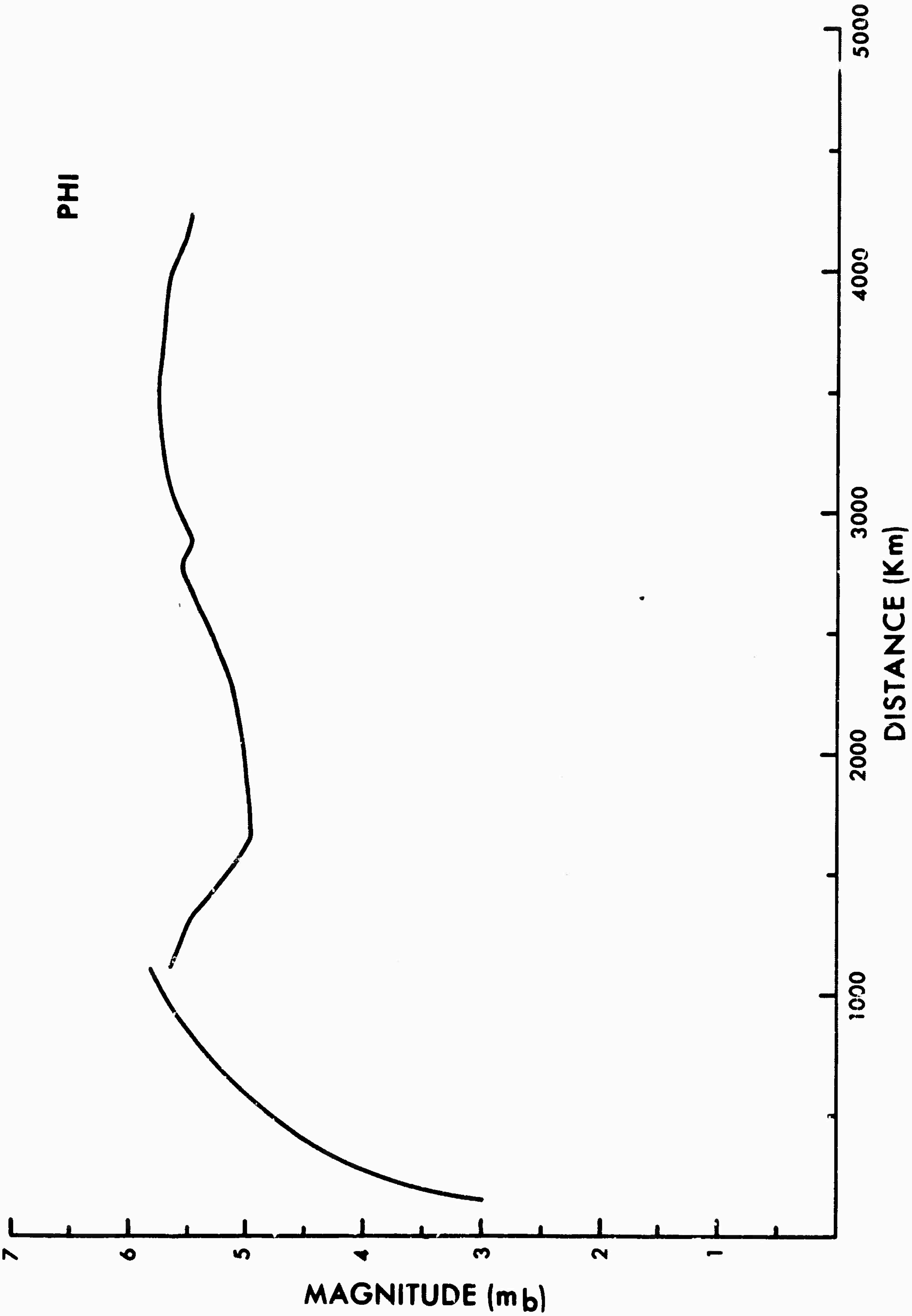

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MAGNITUDE (mb)
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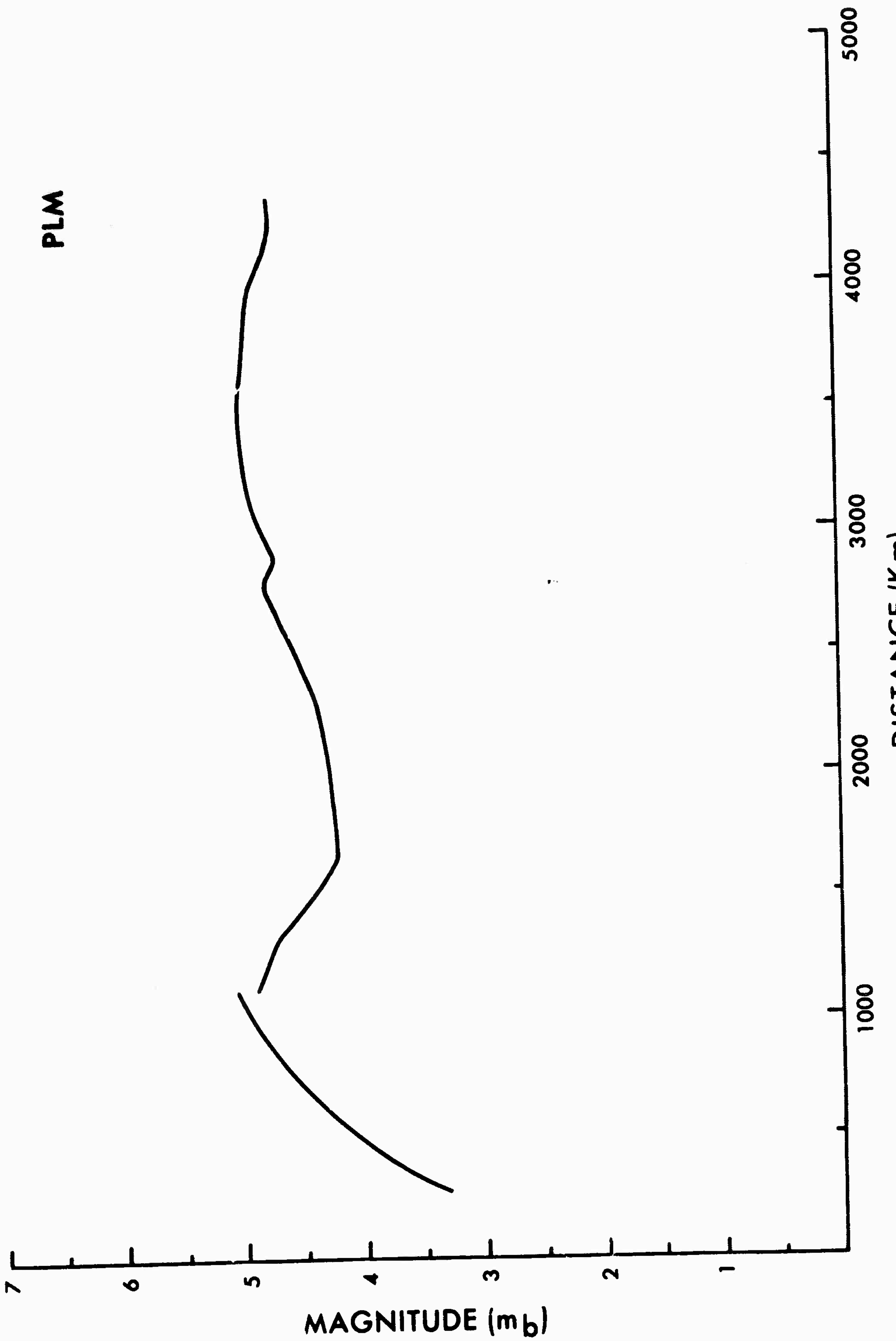
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DISTANCE (Km)
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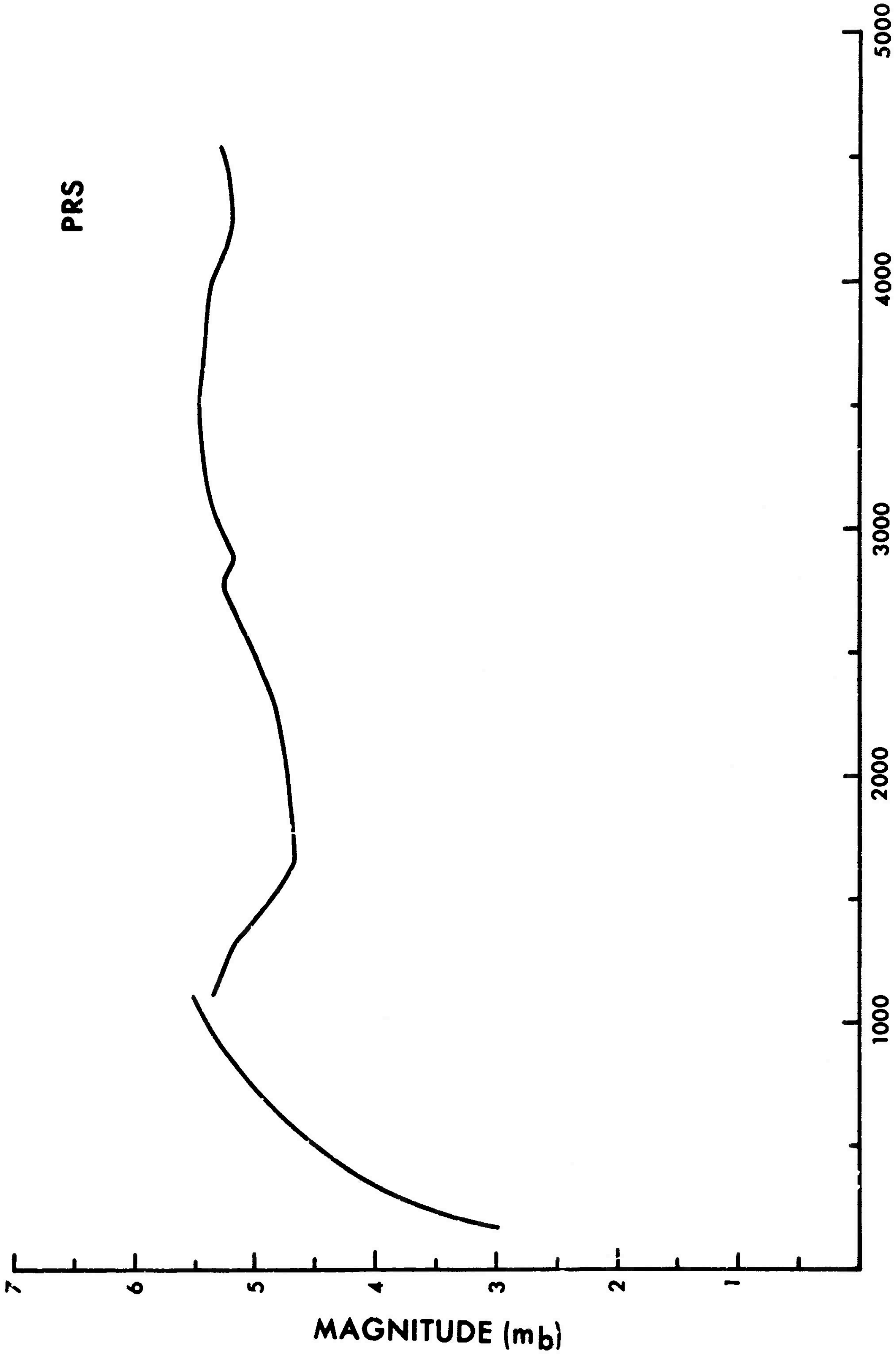
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DISTANCE (Km)
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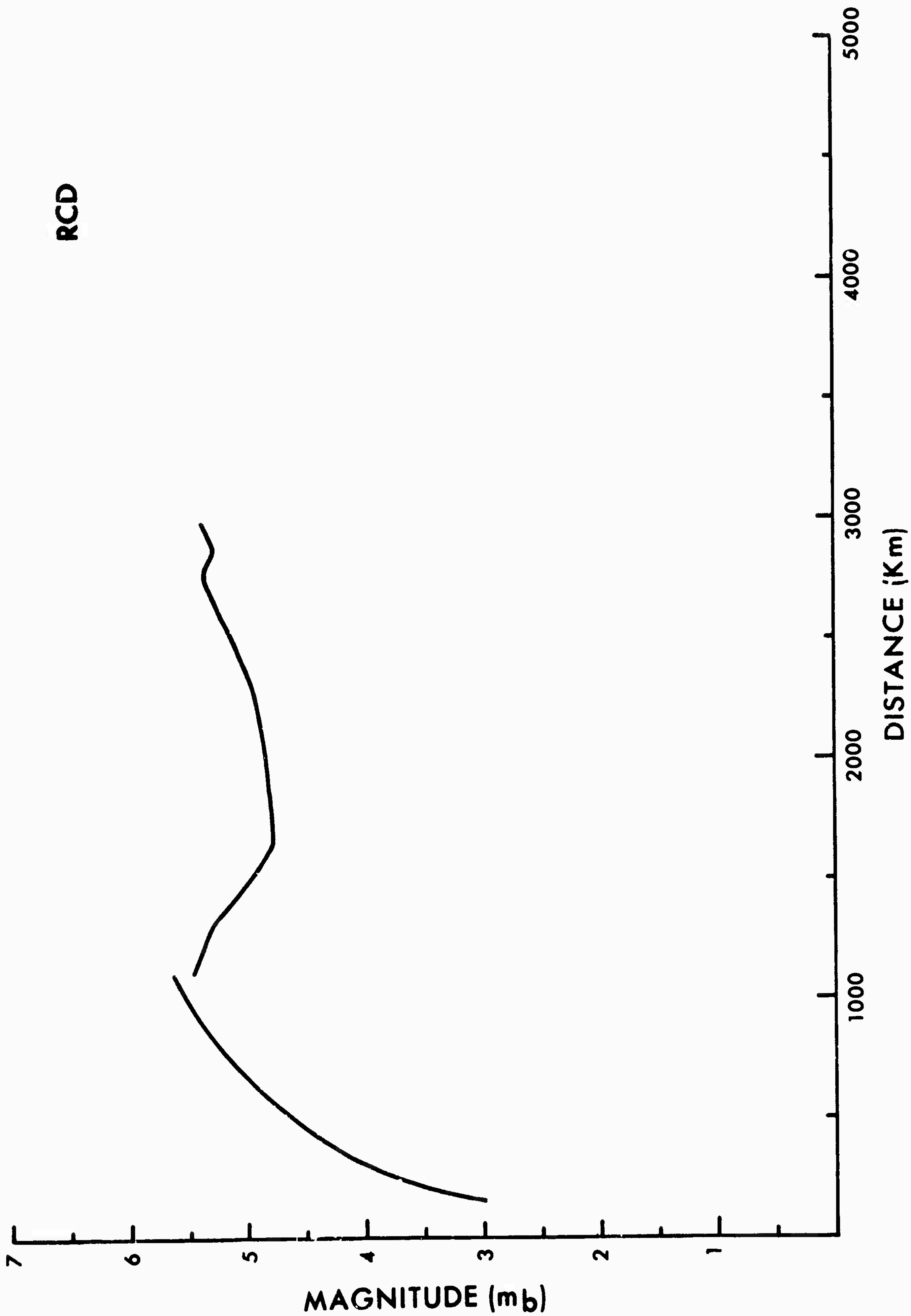
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DISTANCE (Km)
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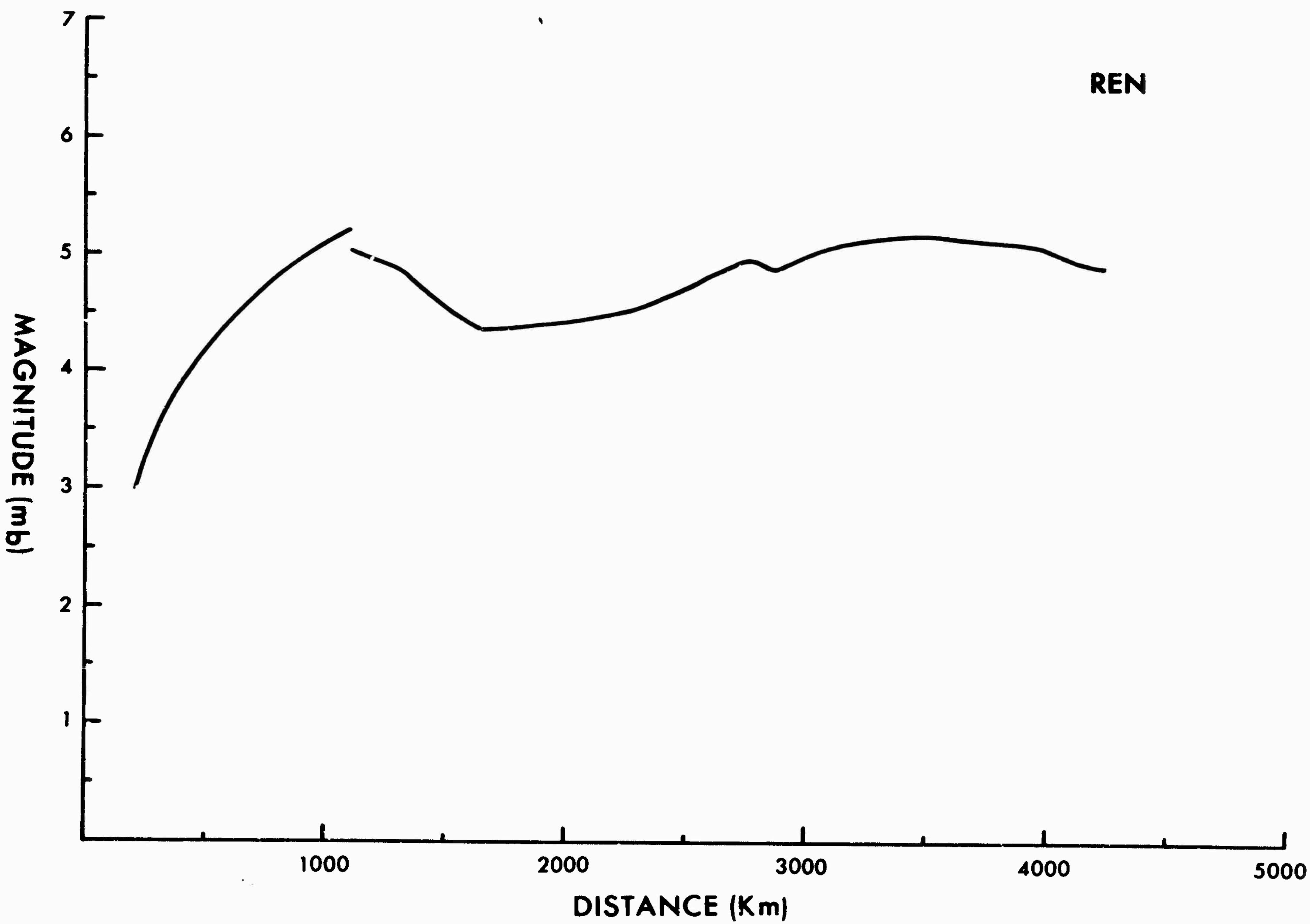
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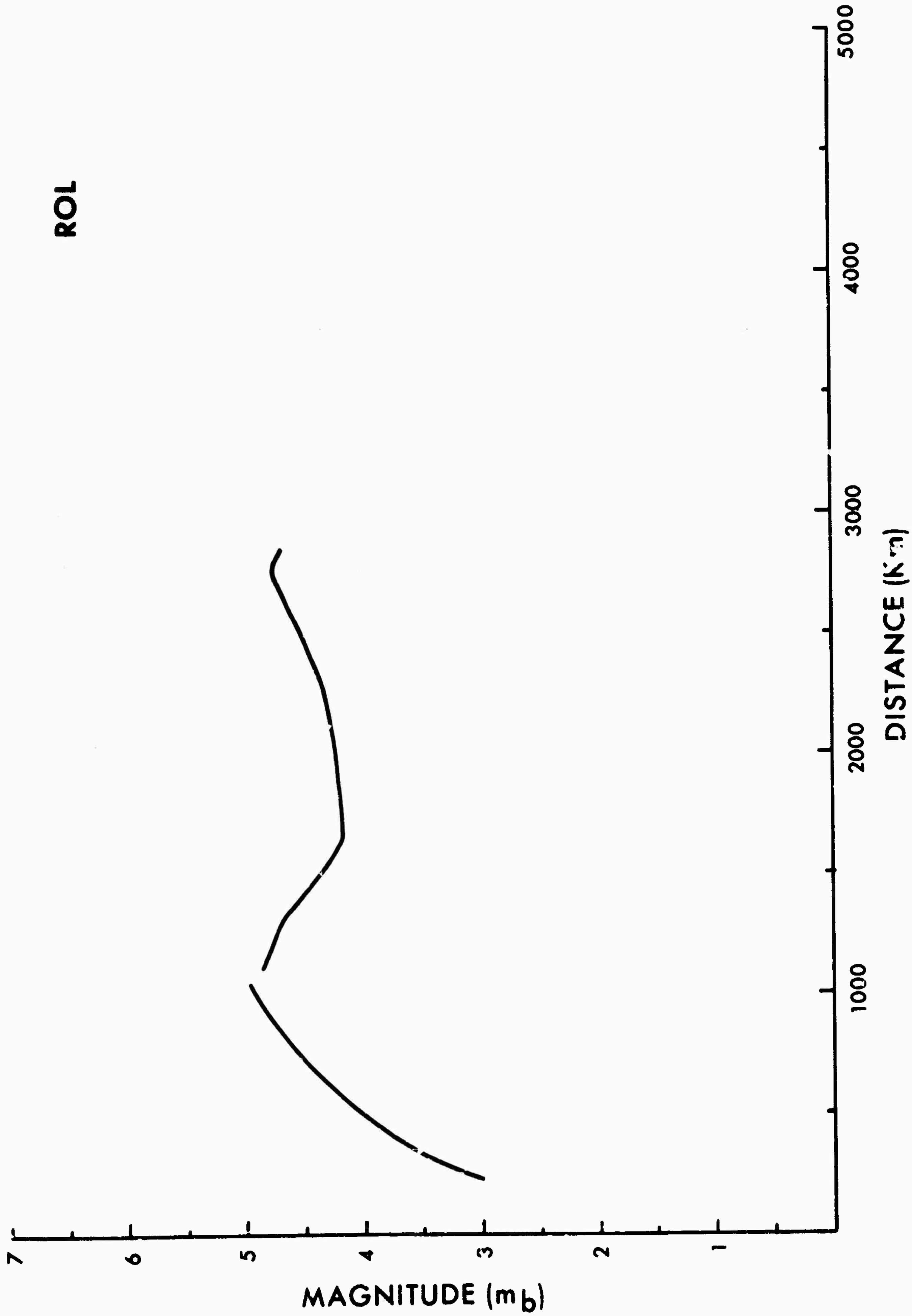
DISTANCE (Km)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DISTANCE (Km)
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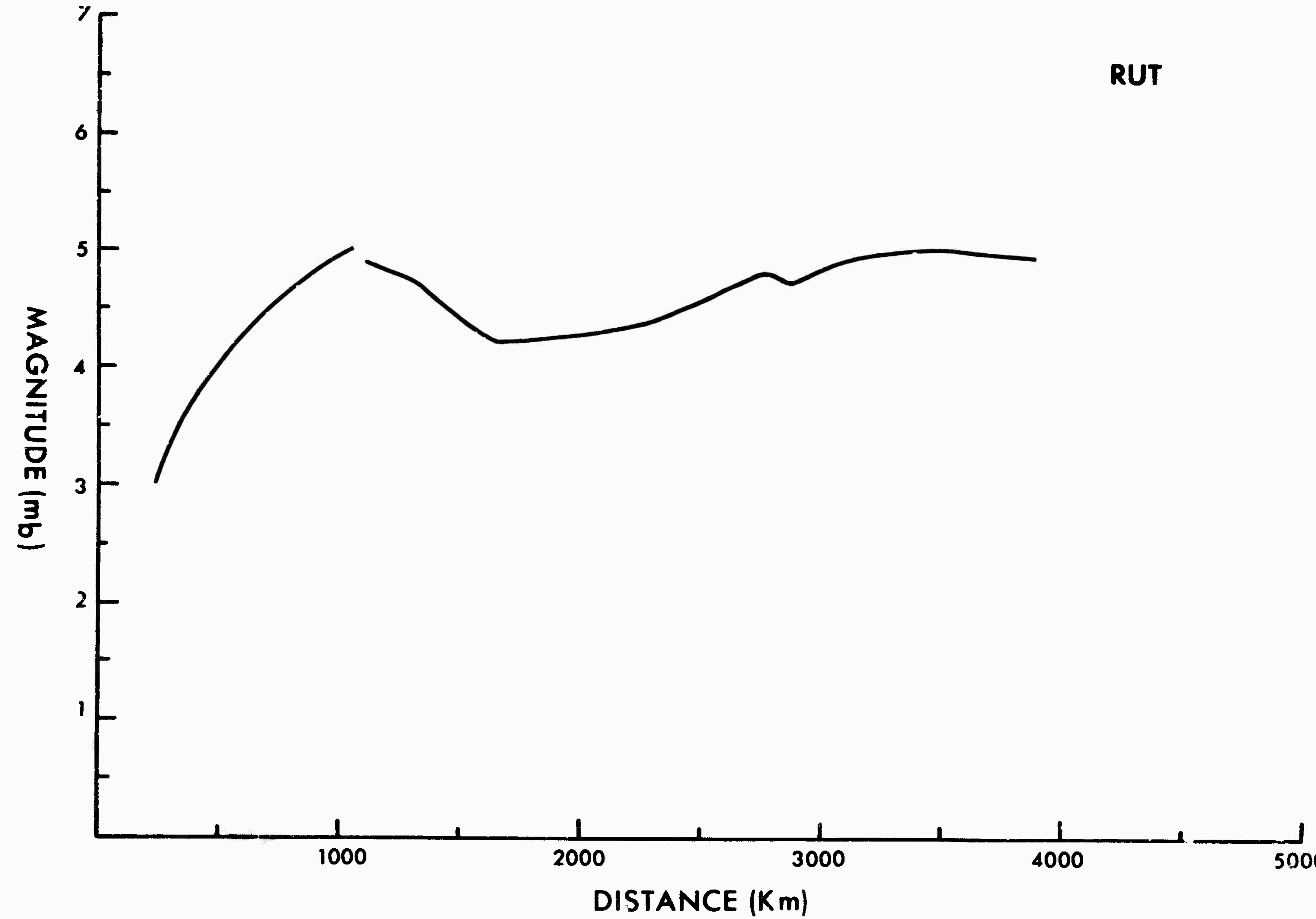
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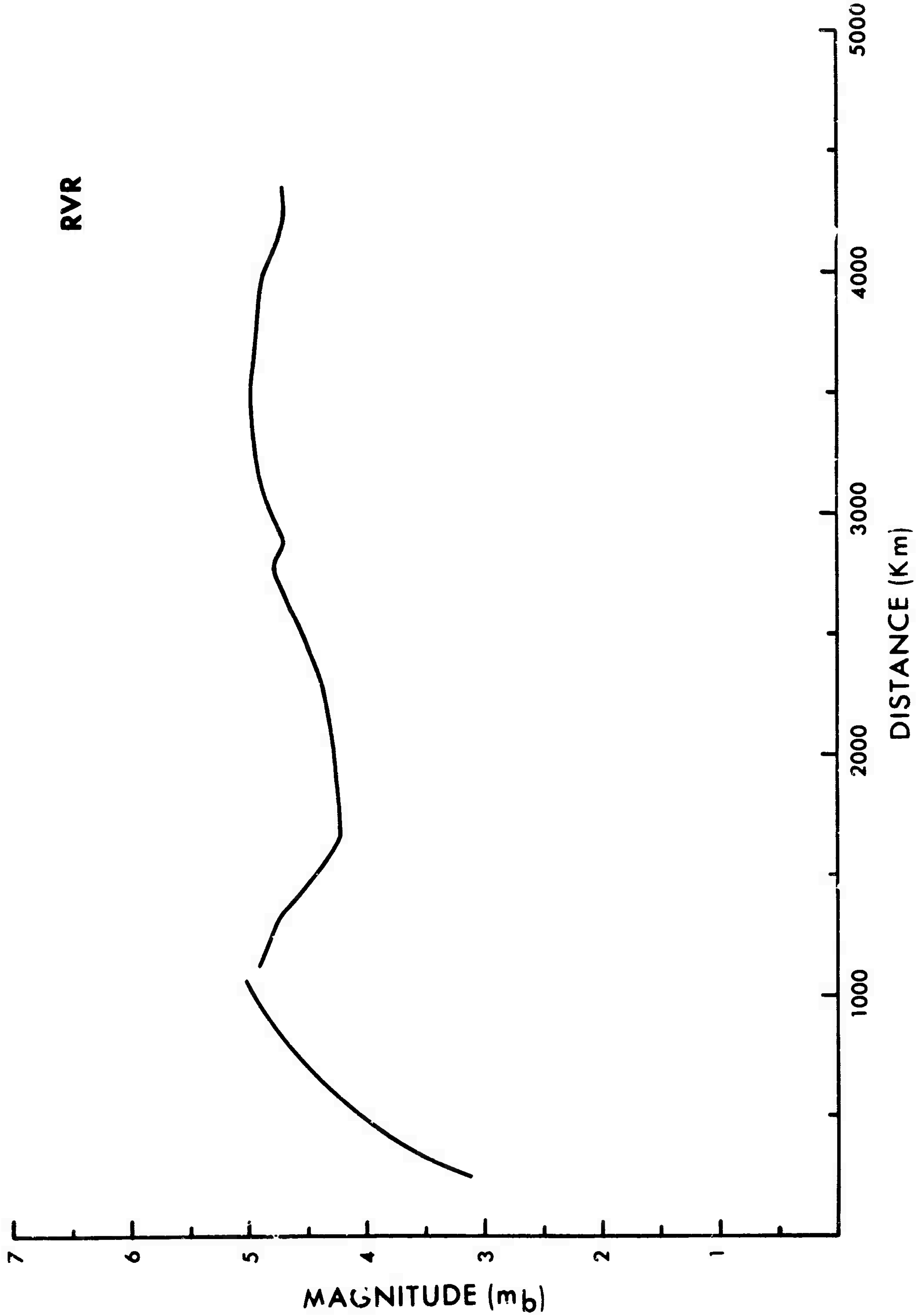
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DISTANCE (Km)
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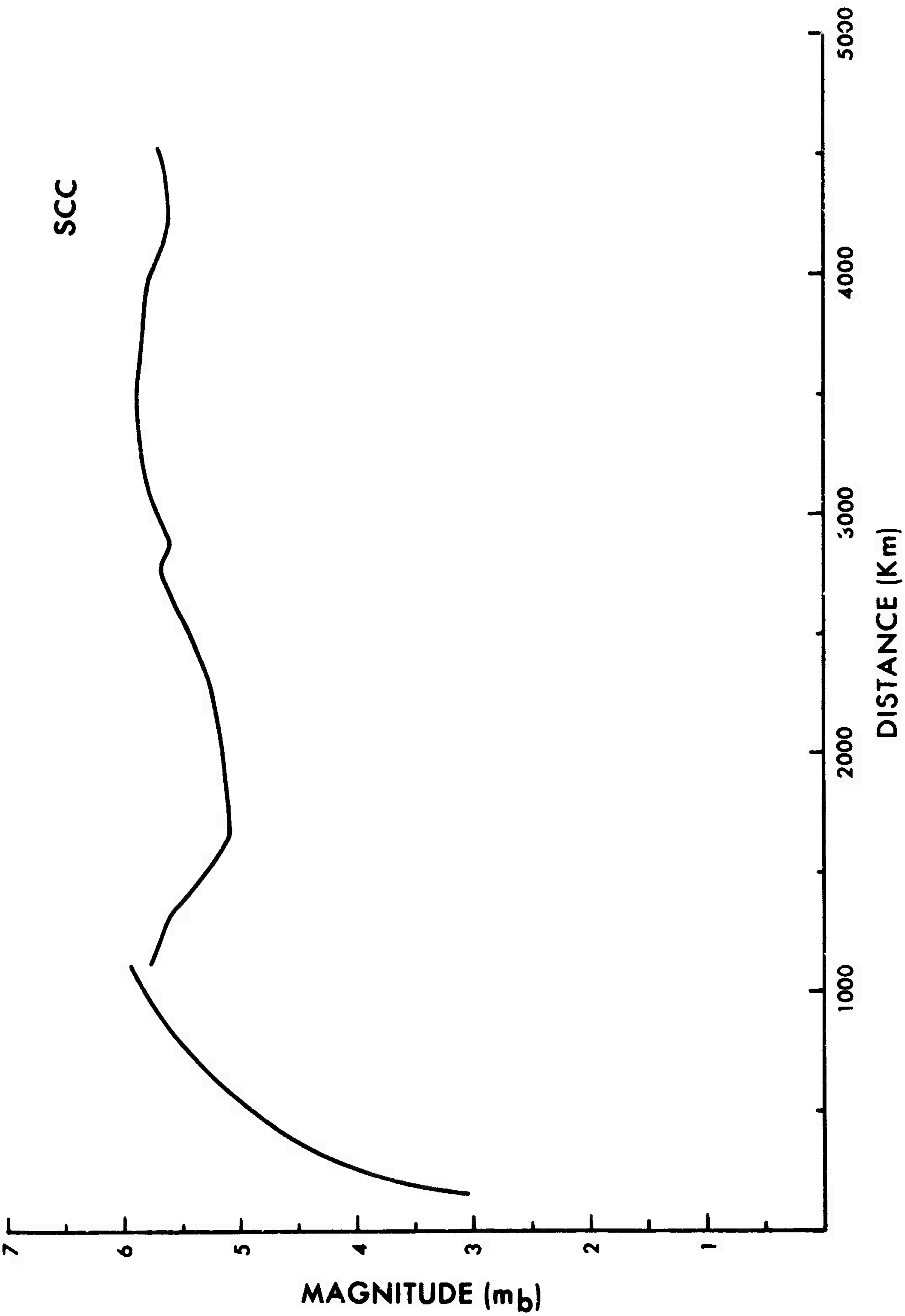
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MAGNITUDE (m_b)
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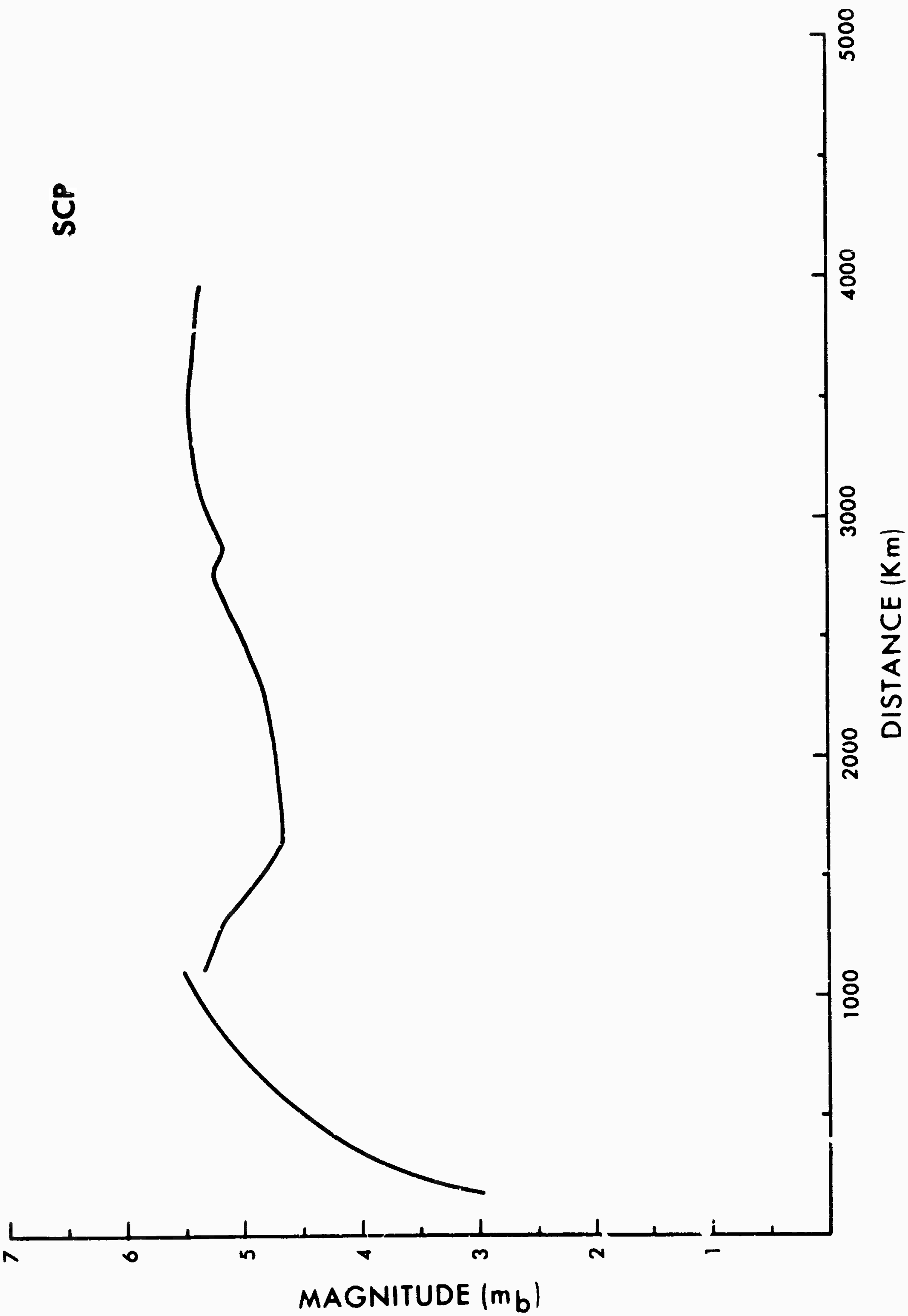

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DISTANCE (Km)
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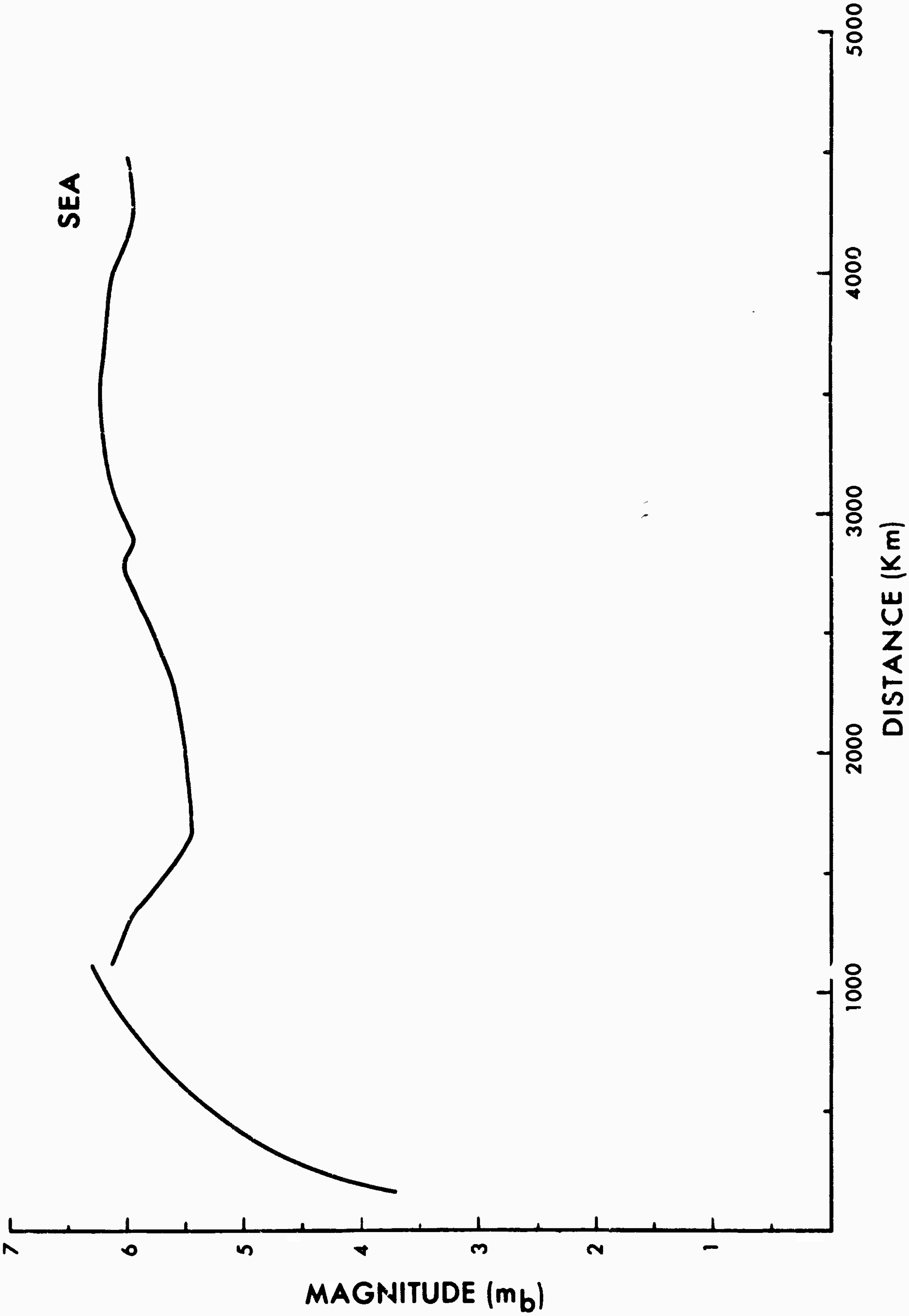
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DISTANCE (Km)
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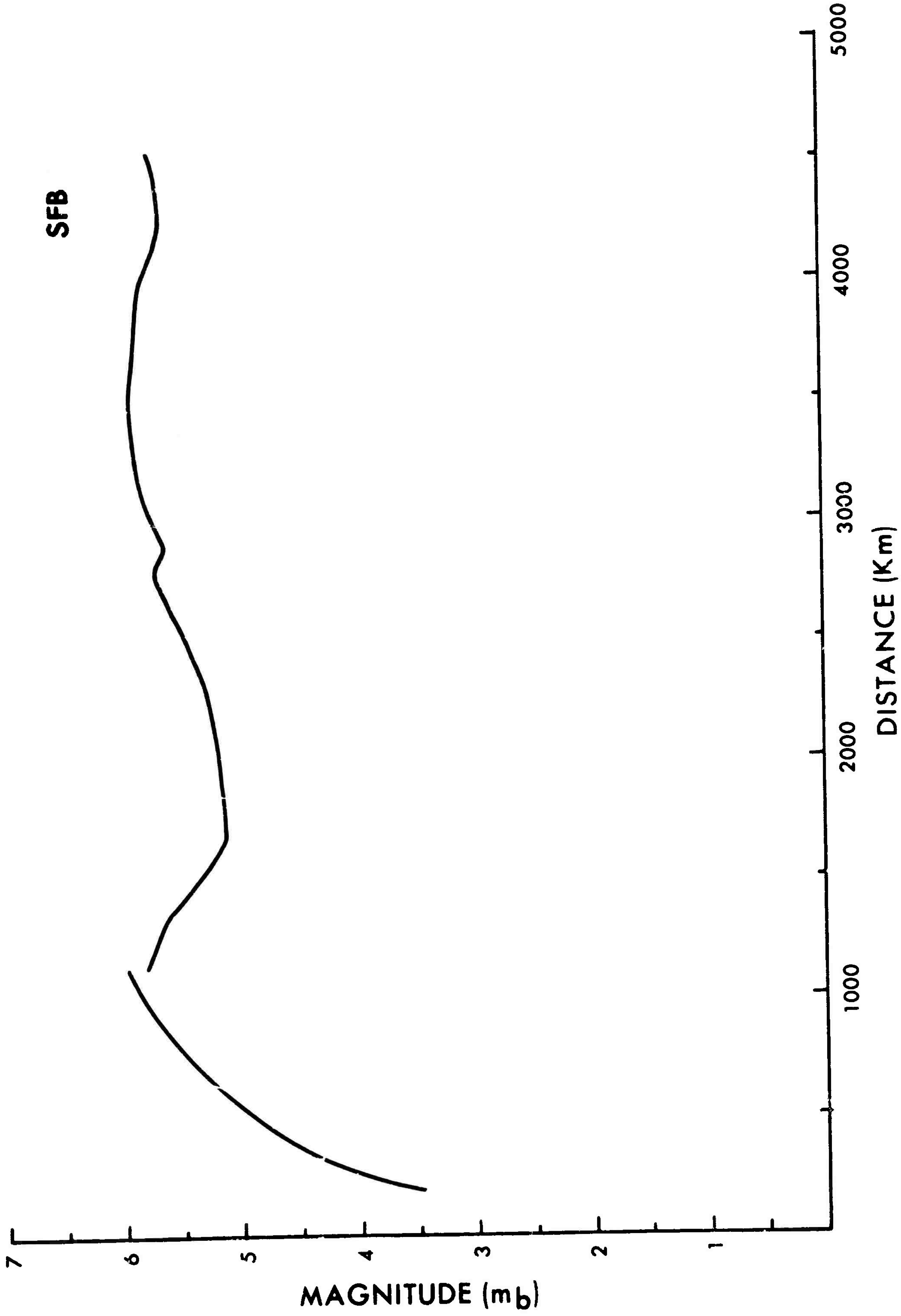
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MAGNITUDE (mb)
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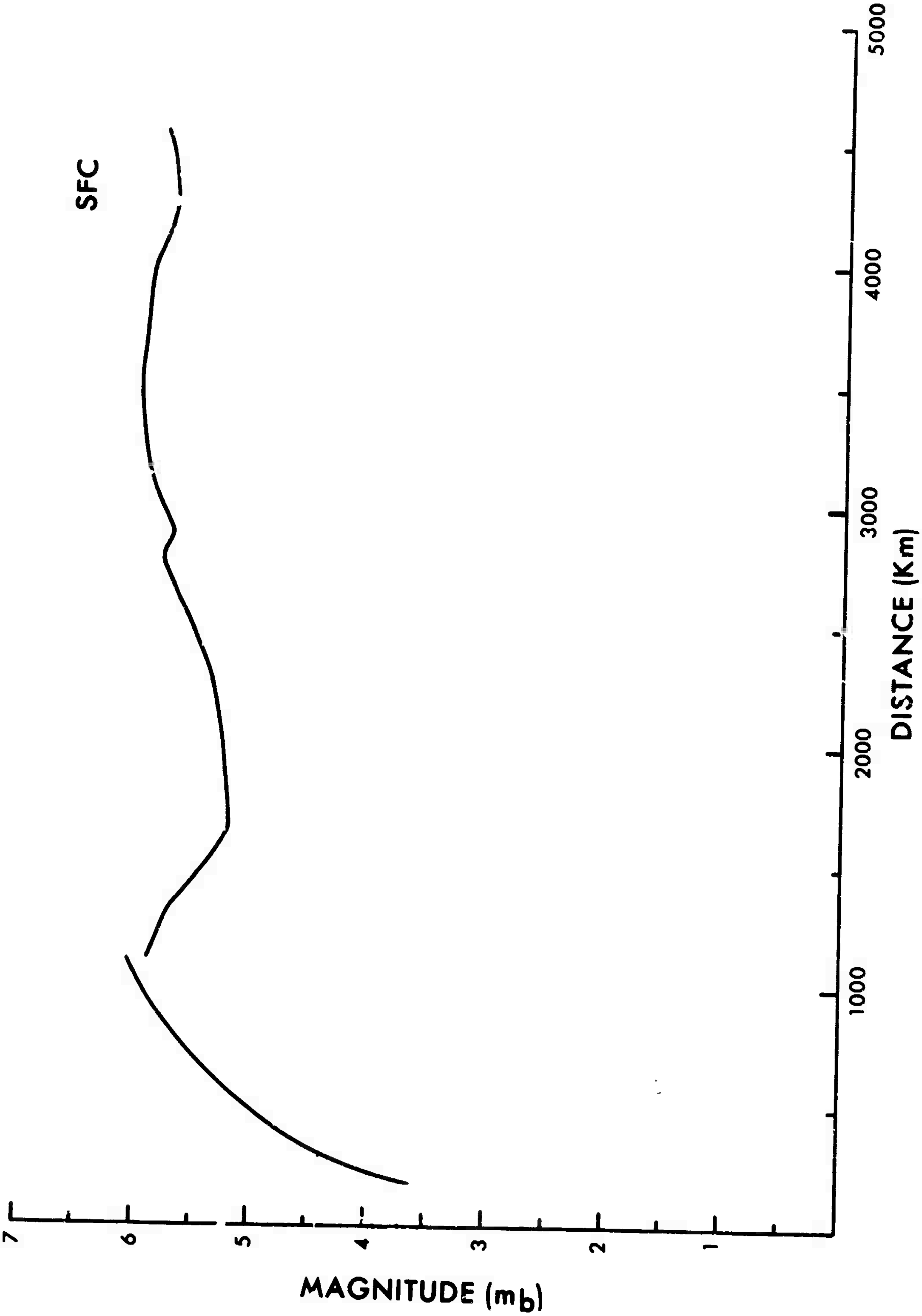
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MAGNITUDE (mb)
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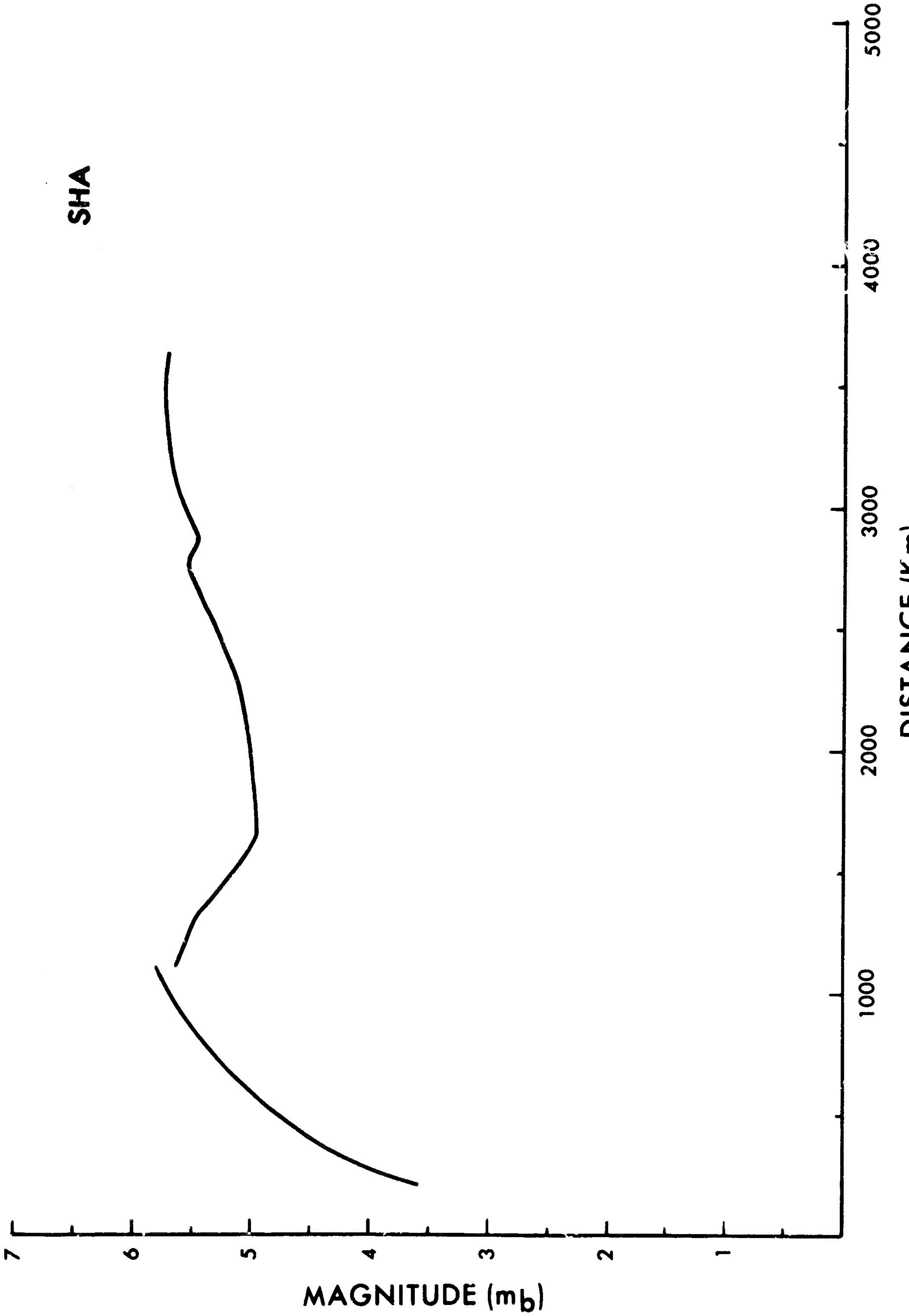
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MAGNITUDE (mb)
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DISTANCE (Km)
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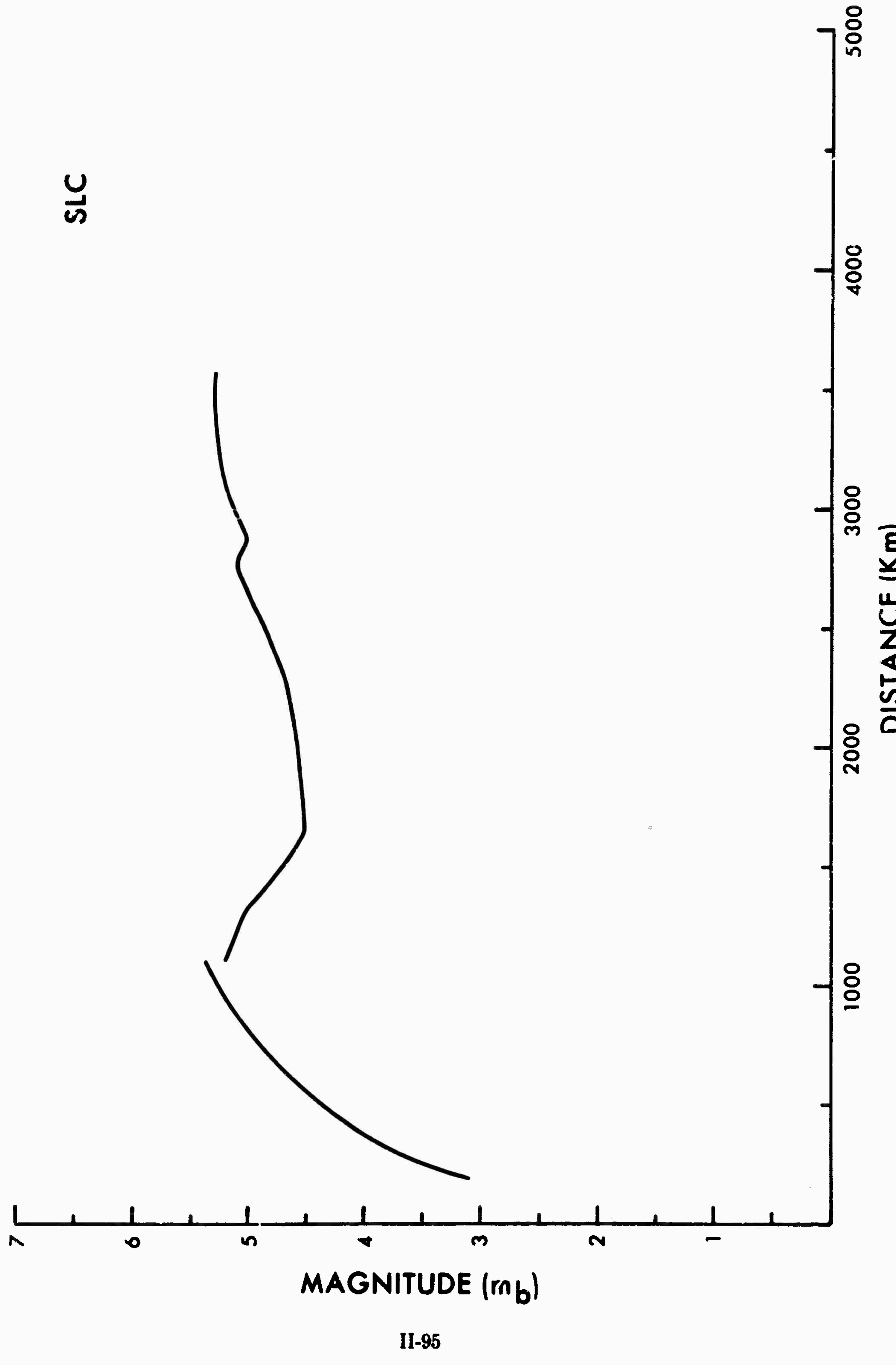

SLC
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DISTANCE (Km)
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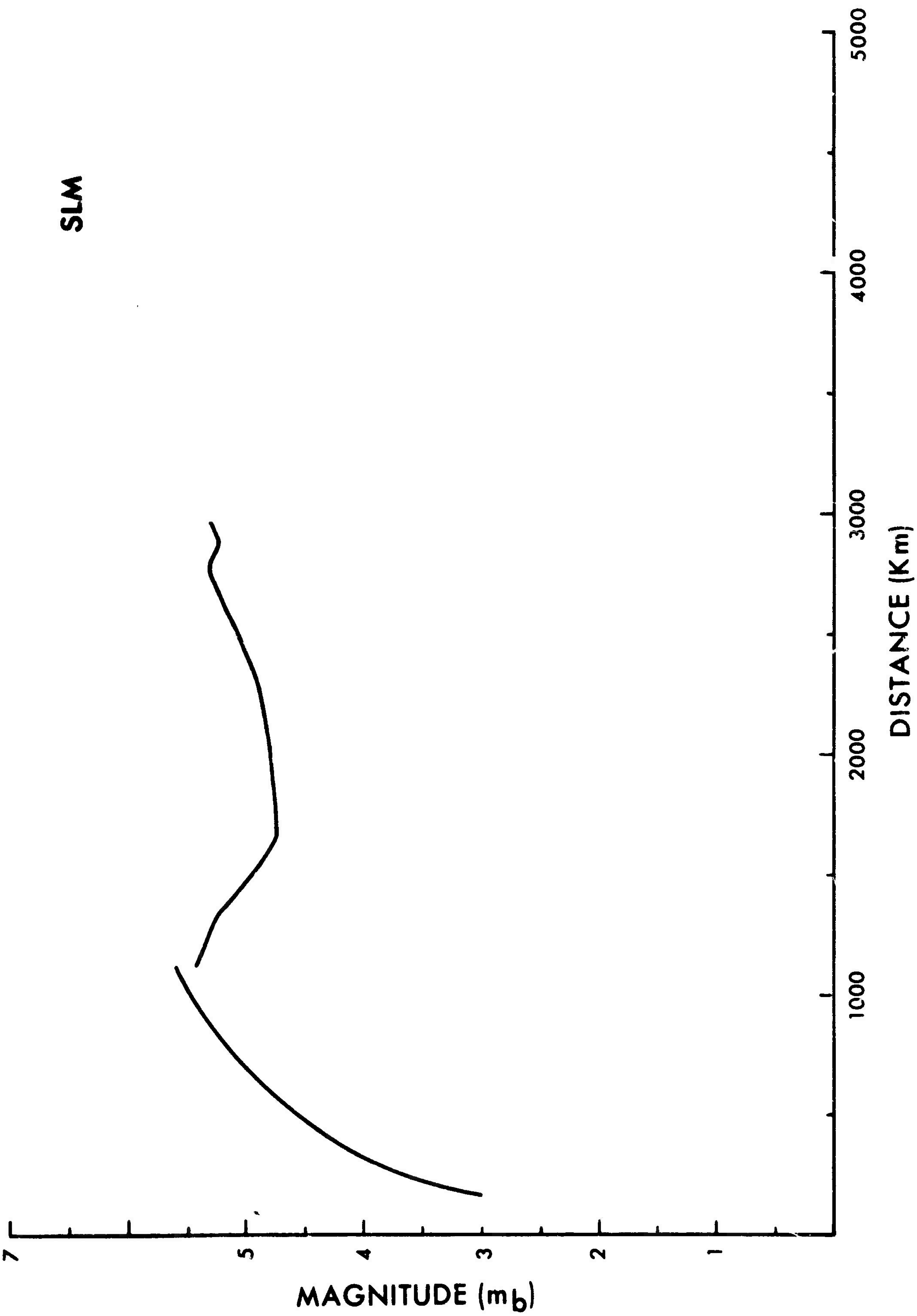
SLM
DISTANCE (Km)
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MAGNITUDE (m_b)
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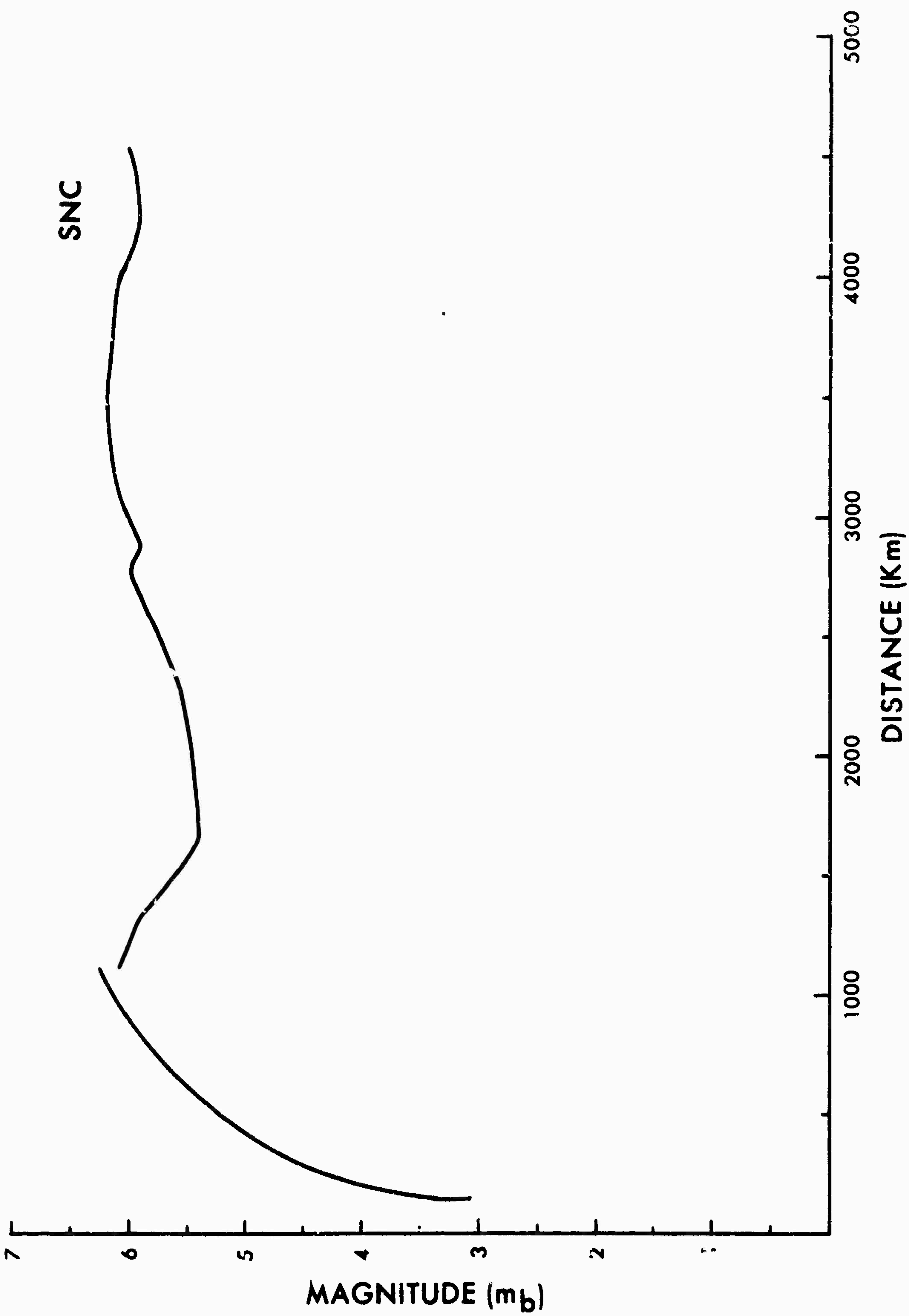
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DISTANCE (Km)
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MAGNITUDE (mb)
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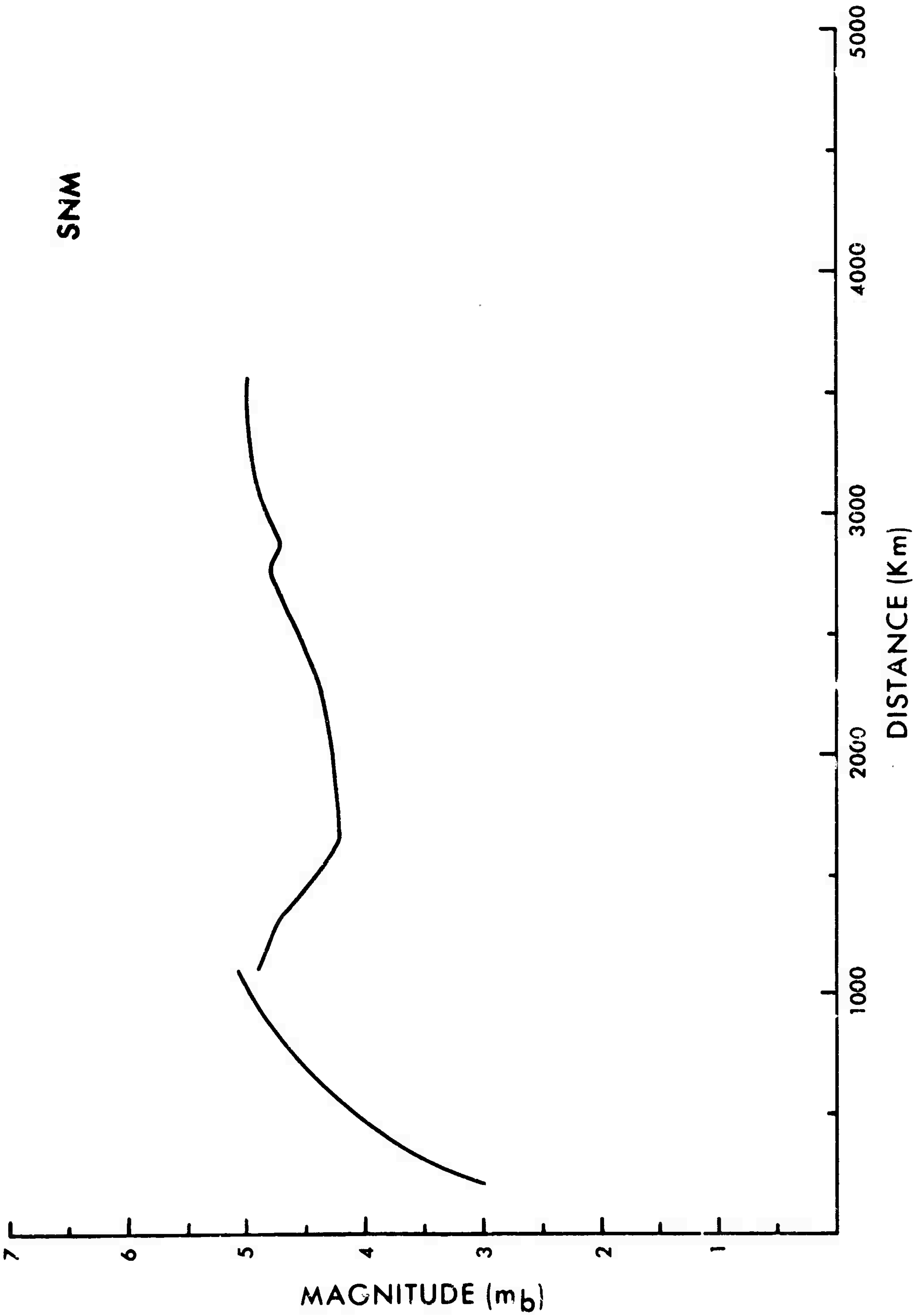

SNM
MAGNITUDE (m_b)
DISTANCE (Km)
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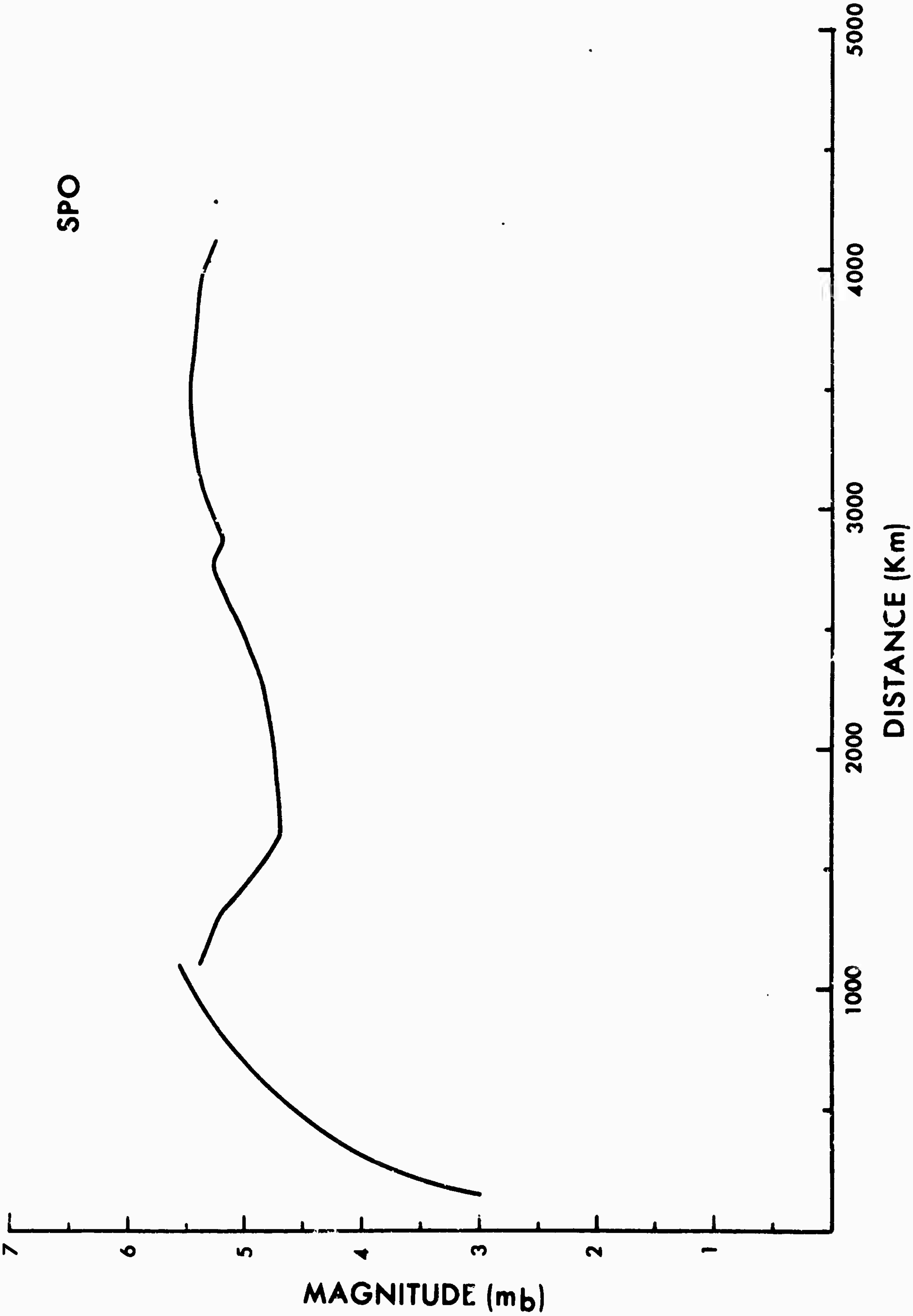
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MAGNITUDE (mb)
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DISTANCE (Km)
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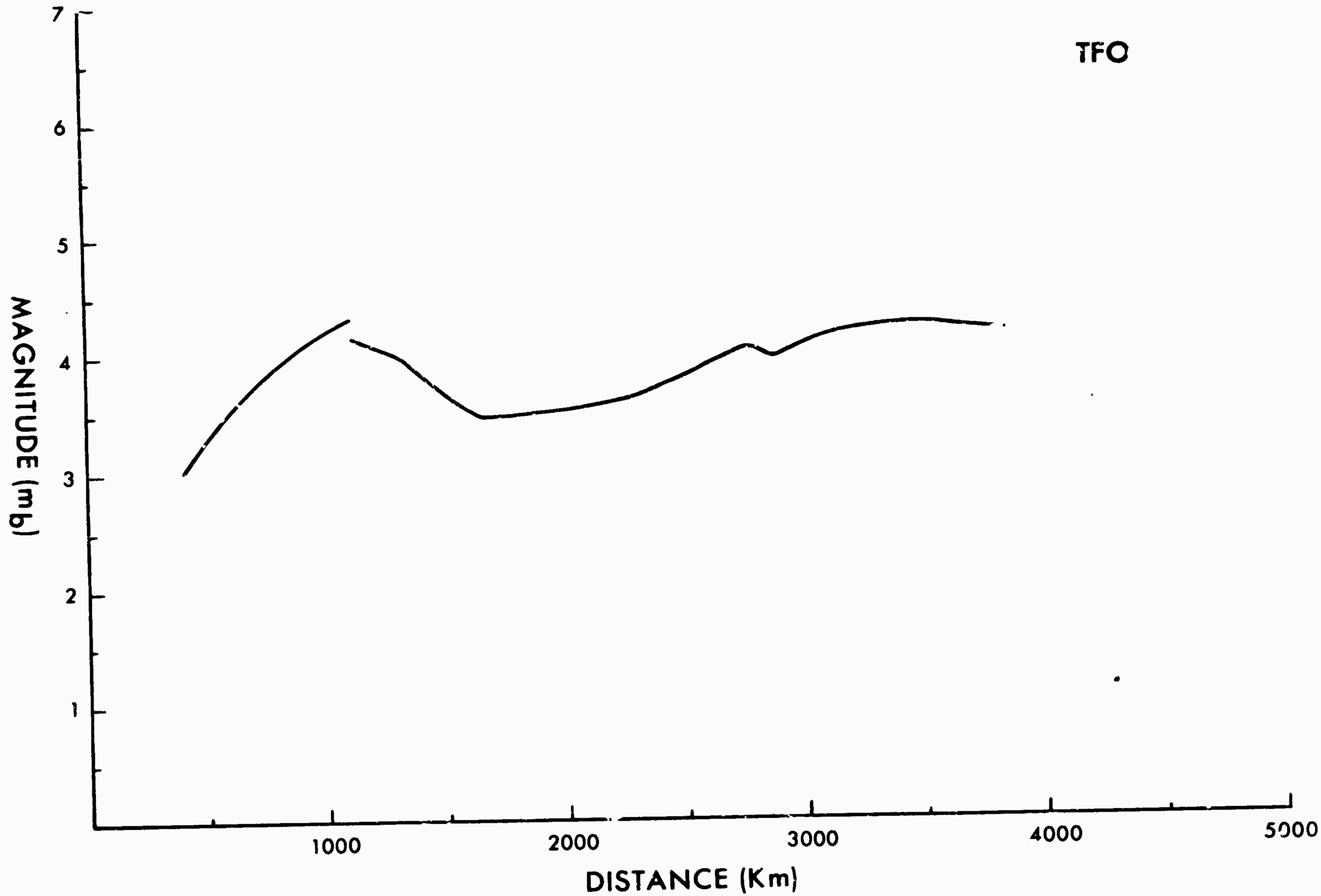
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MAGNITUDE (m_b)
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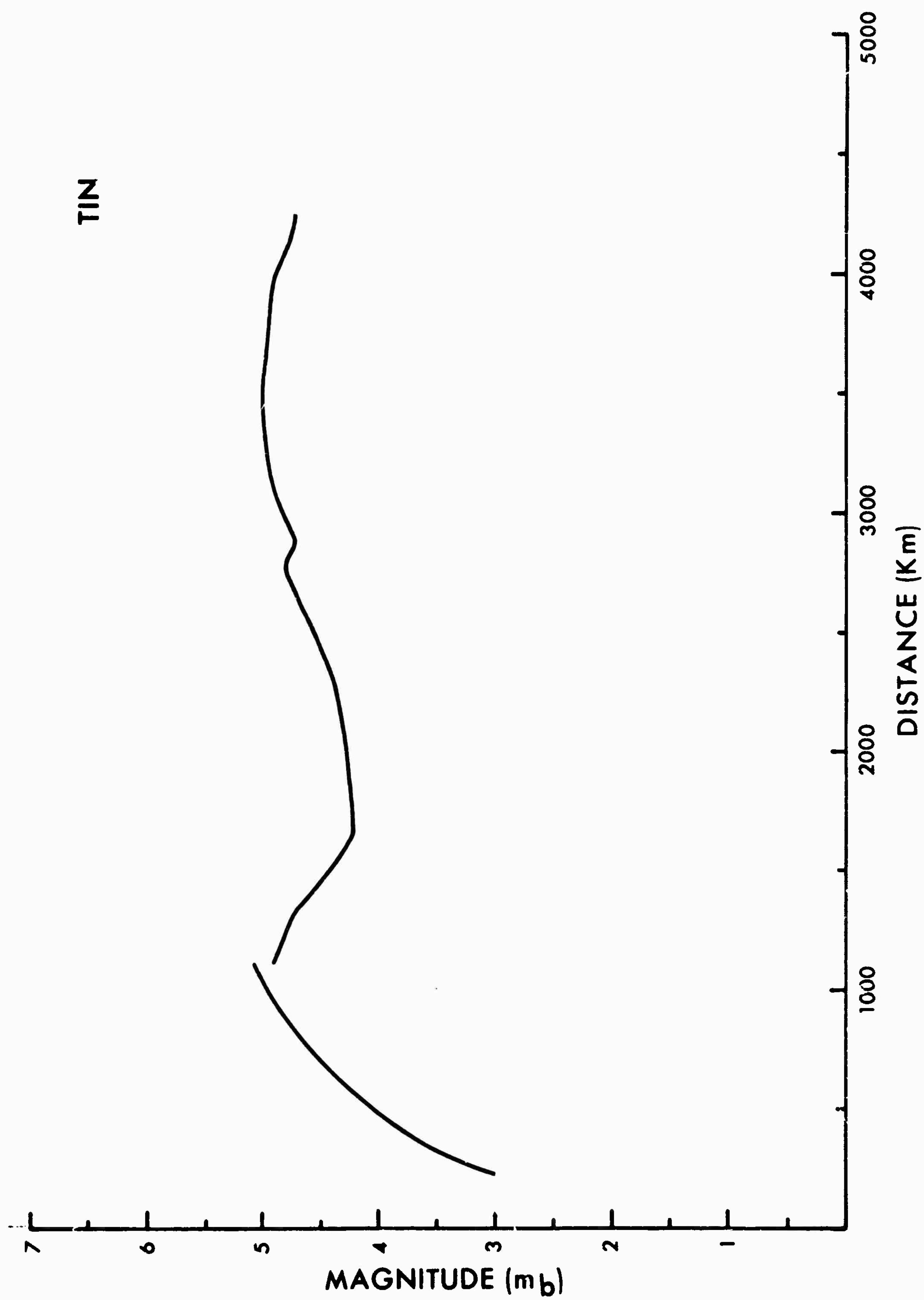
5000
DISTANCE (Km)


TIN
MAGNITUDE (m_b)
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4
3
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DISTANCE (Km)
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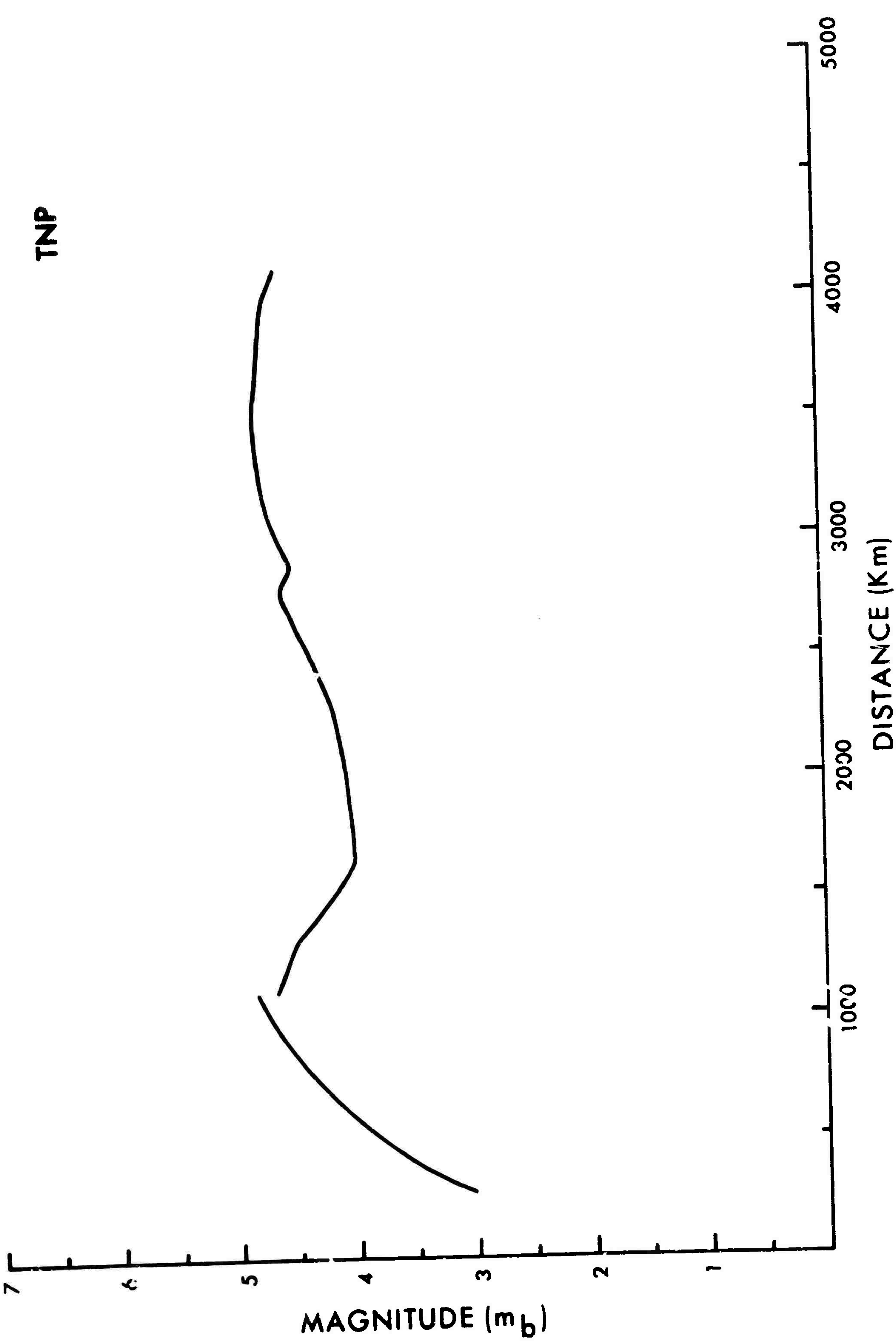
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MAGNITUDE (m_b)
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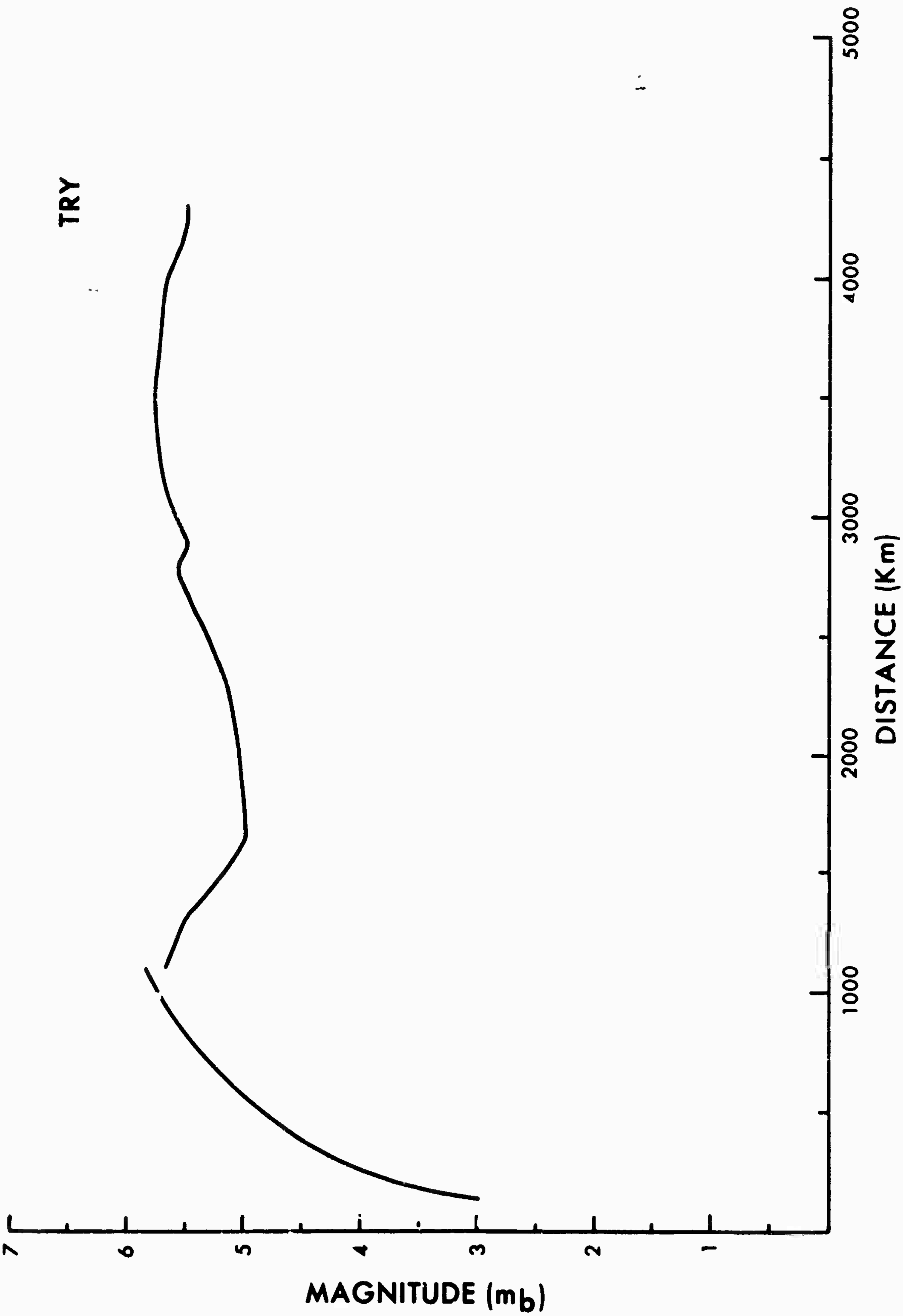
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MAGNITUDE (m_b)
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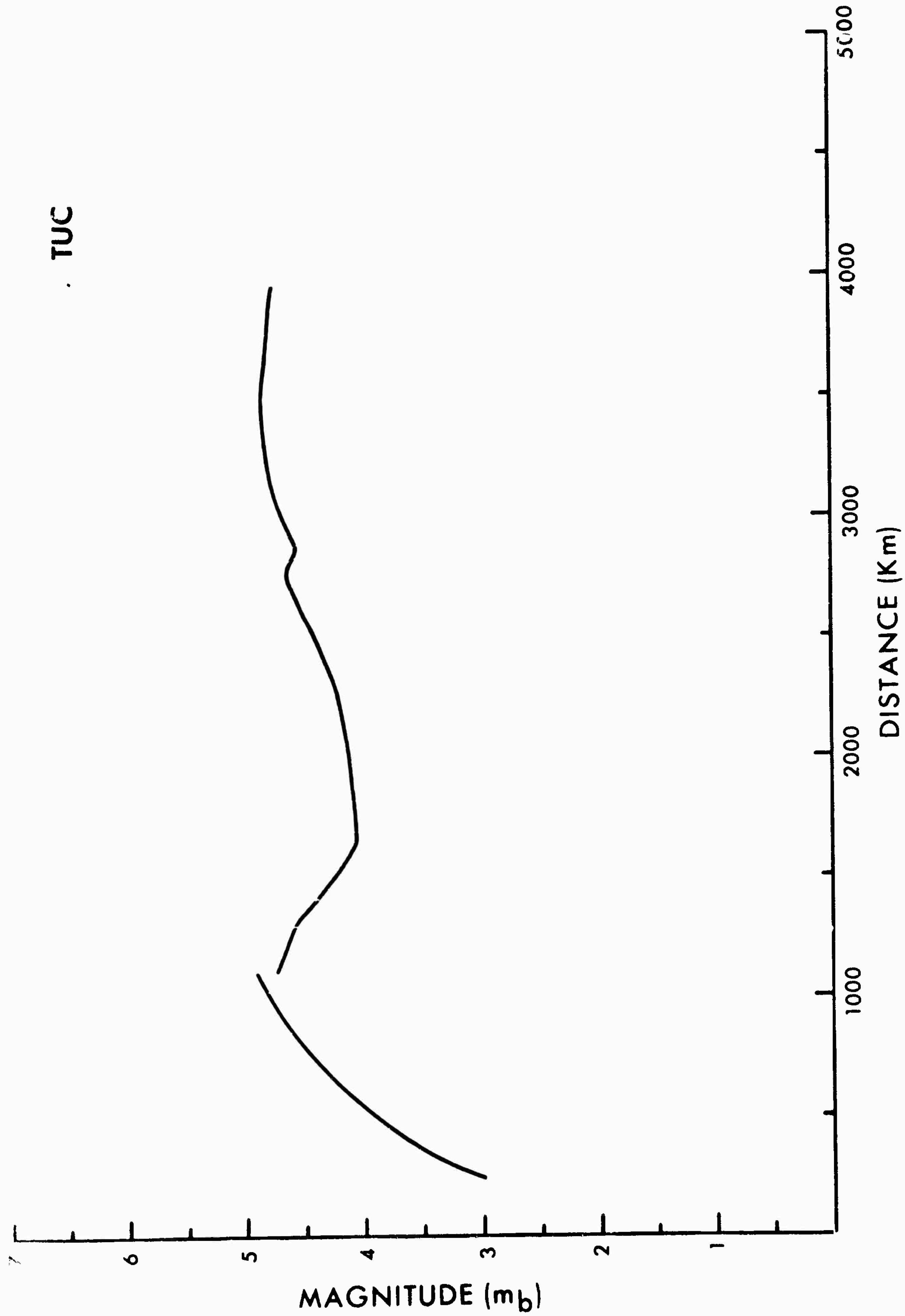
DISTANCE (Km)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DISTANCE (Km)
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MAGNITUDE (m_b)
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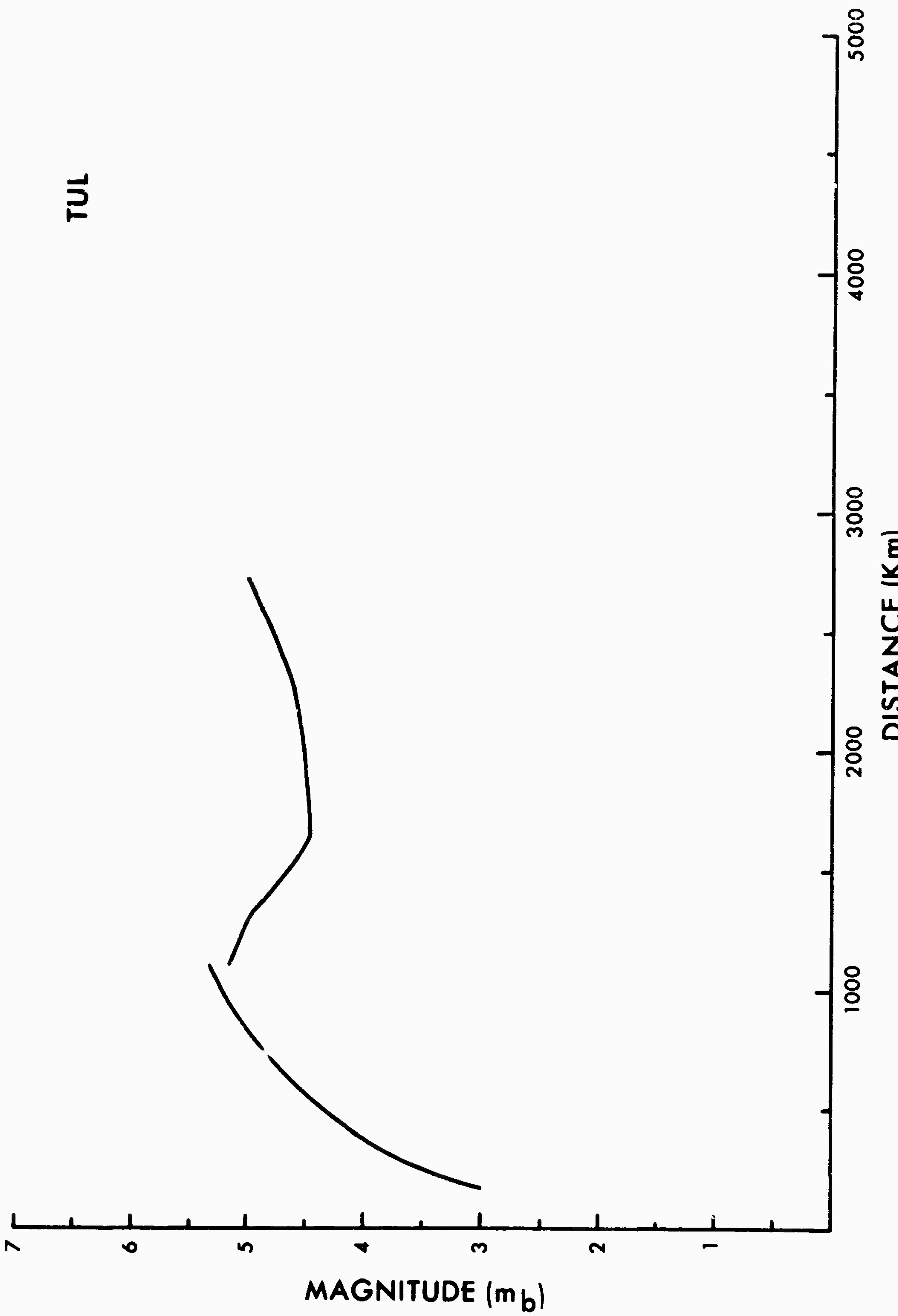
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DISTANCE (Km)
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MAGNITUDE (m_b)
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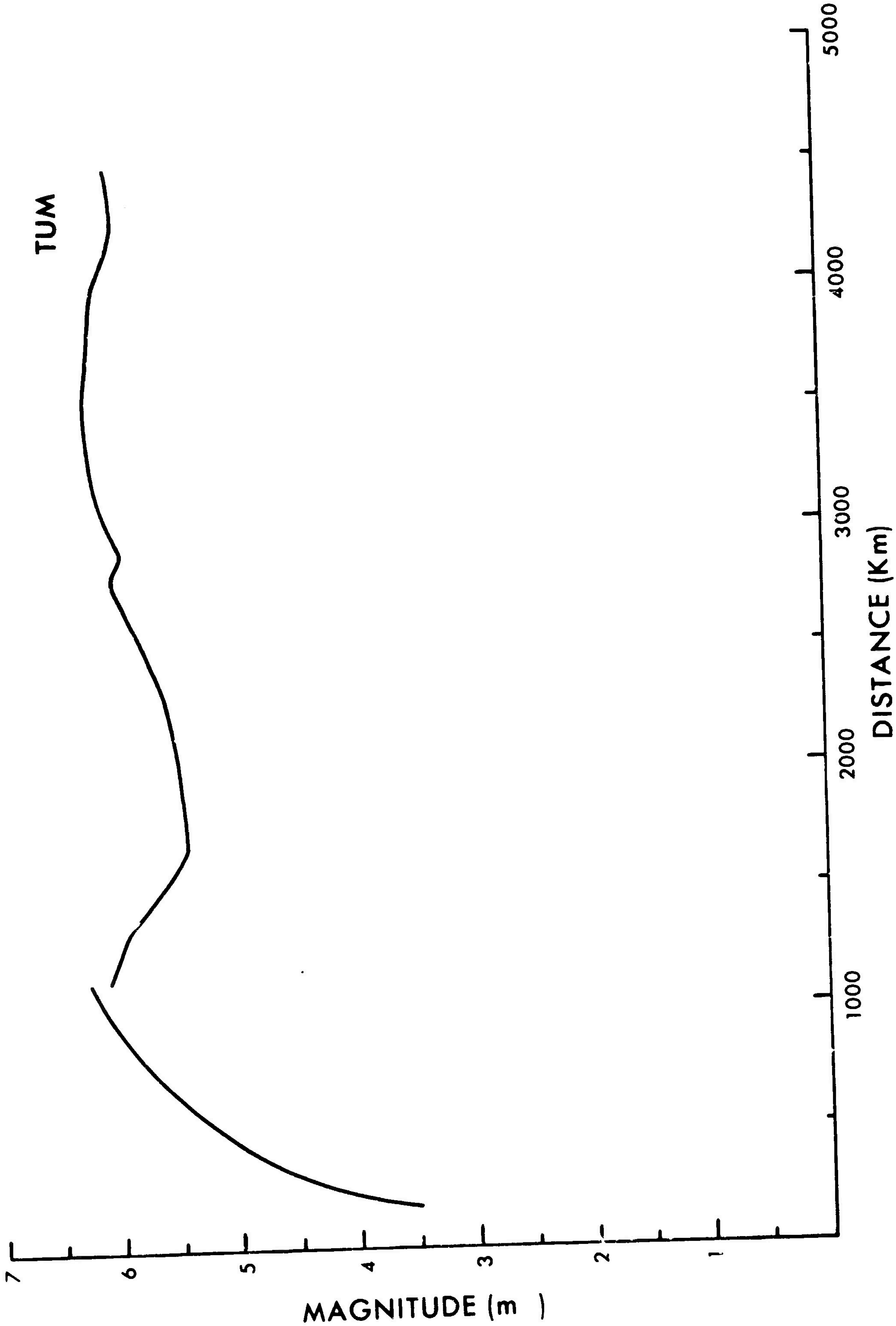
TUM
MAGNITUDE (m)
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DISTANCE (Km)
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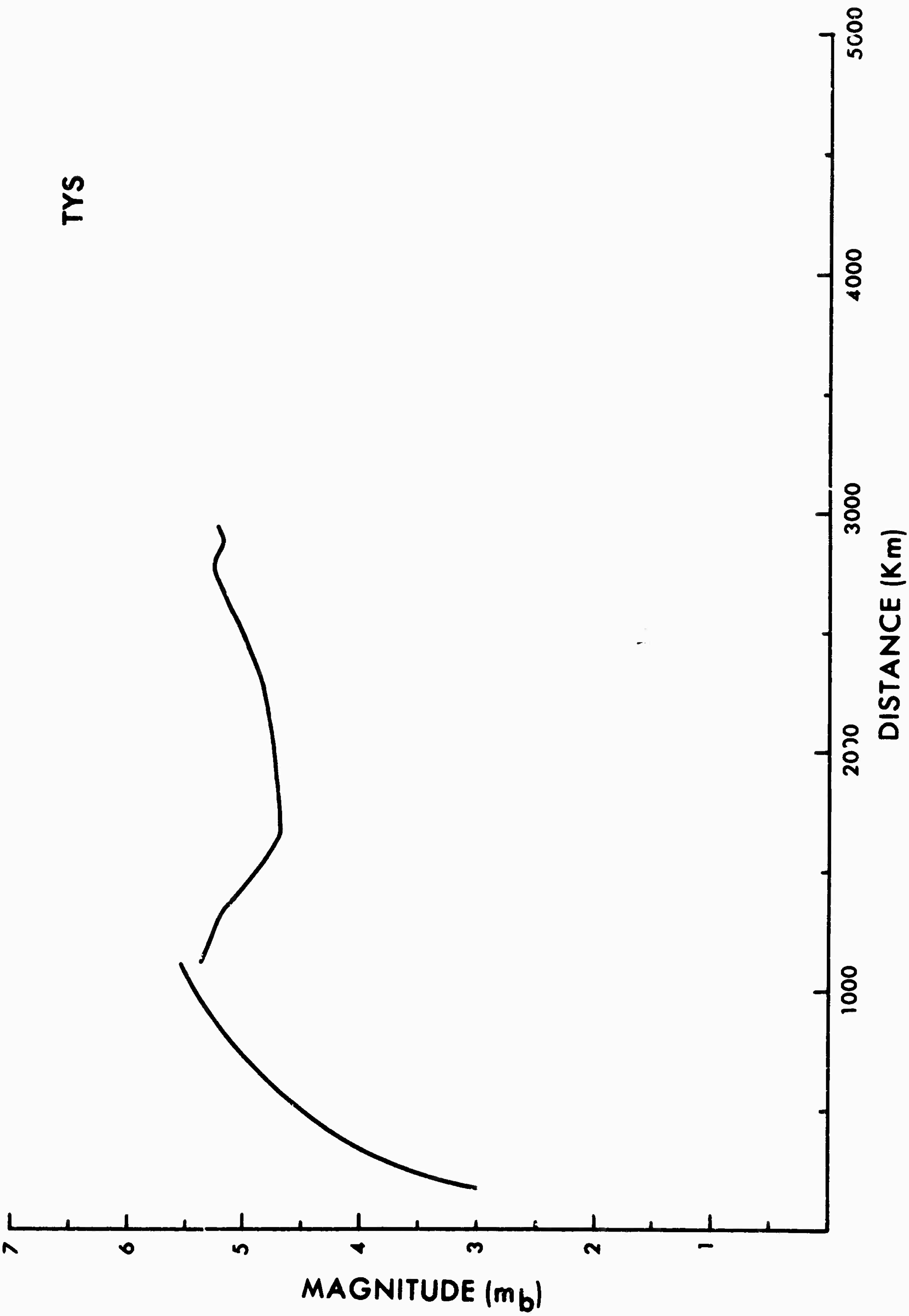
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MAGNITUDE (mb)
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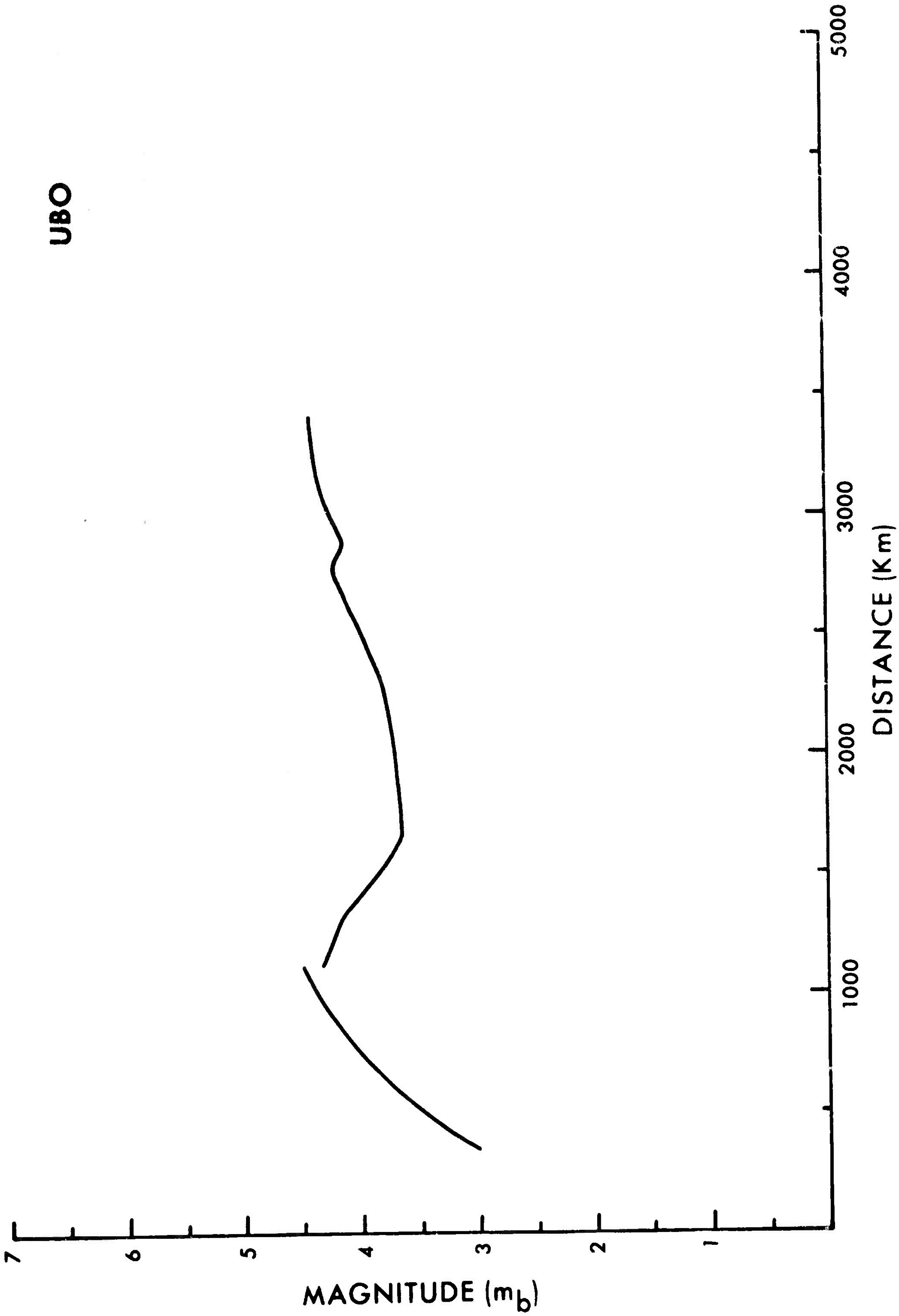
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MAGNITUDE (m_b)
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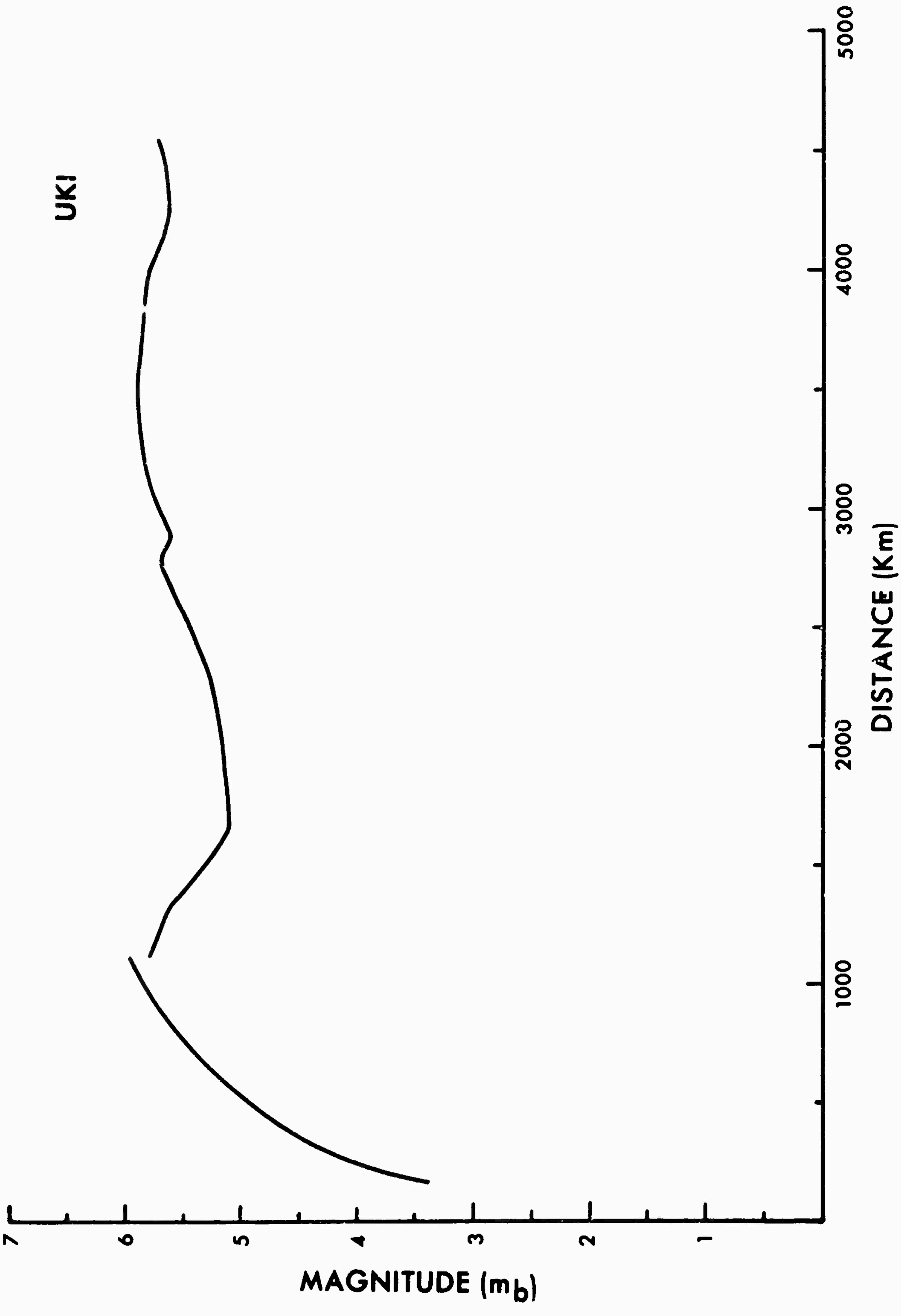
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DISTANCE (Km)
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MAGNITUDE (mb)
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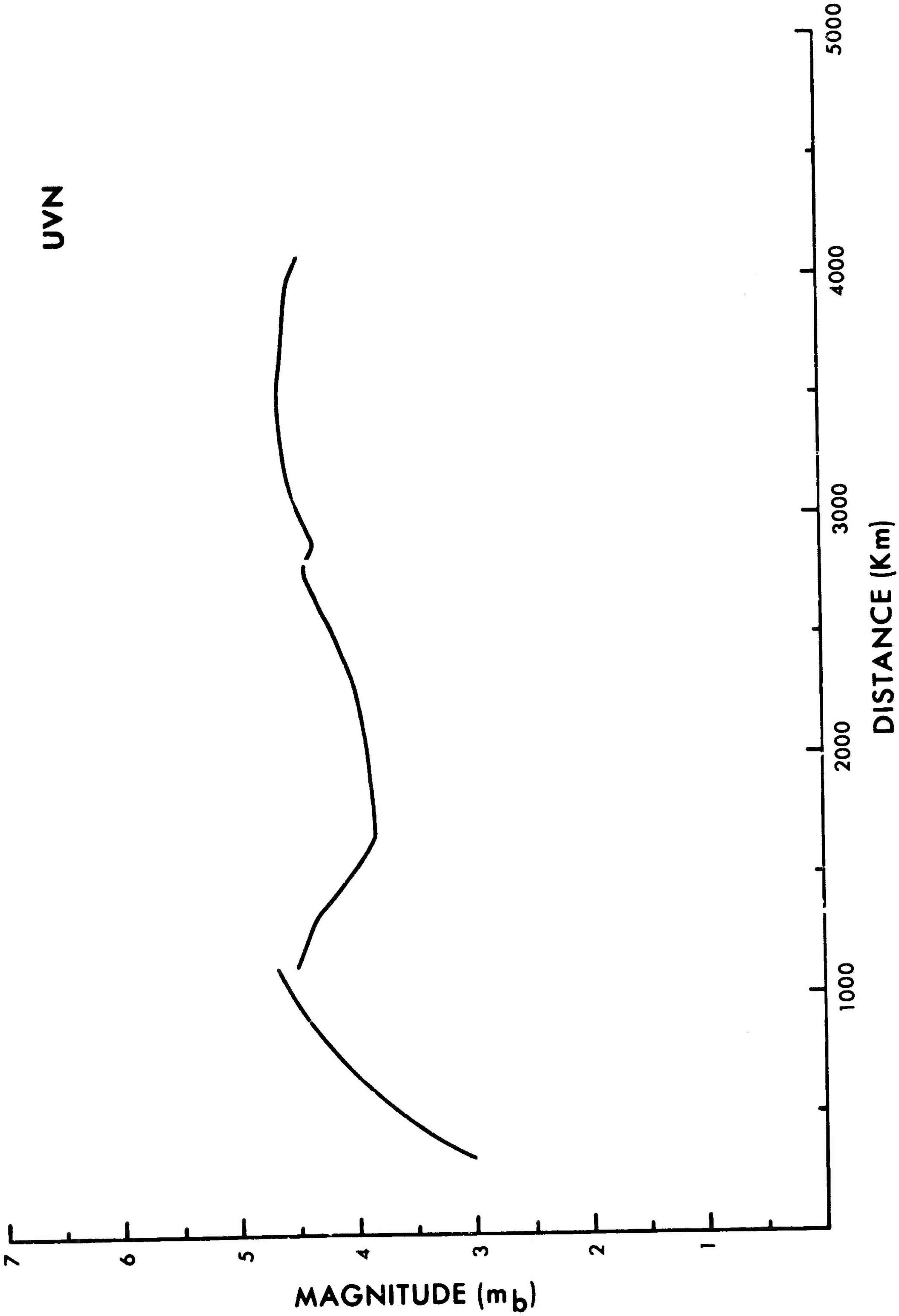
UVN
DISTANCE (Km)
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MAGNITUDE (m_b)
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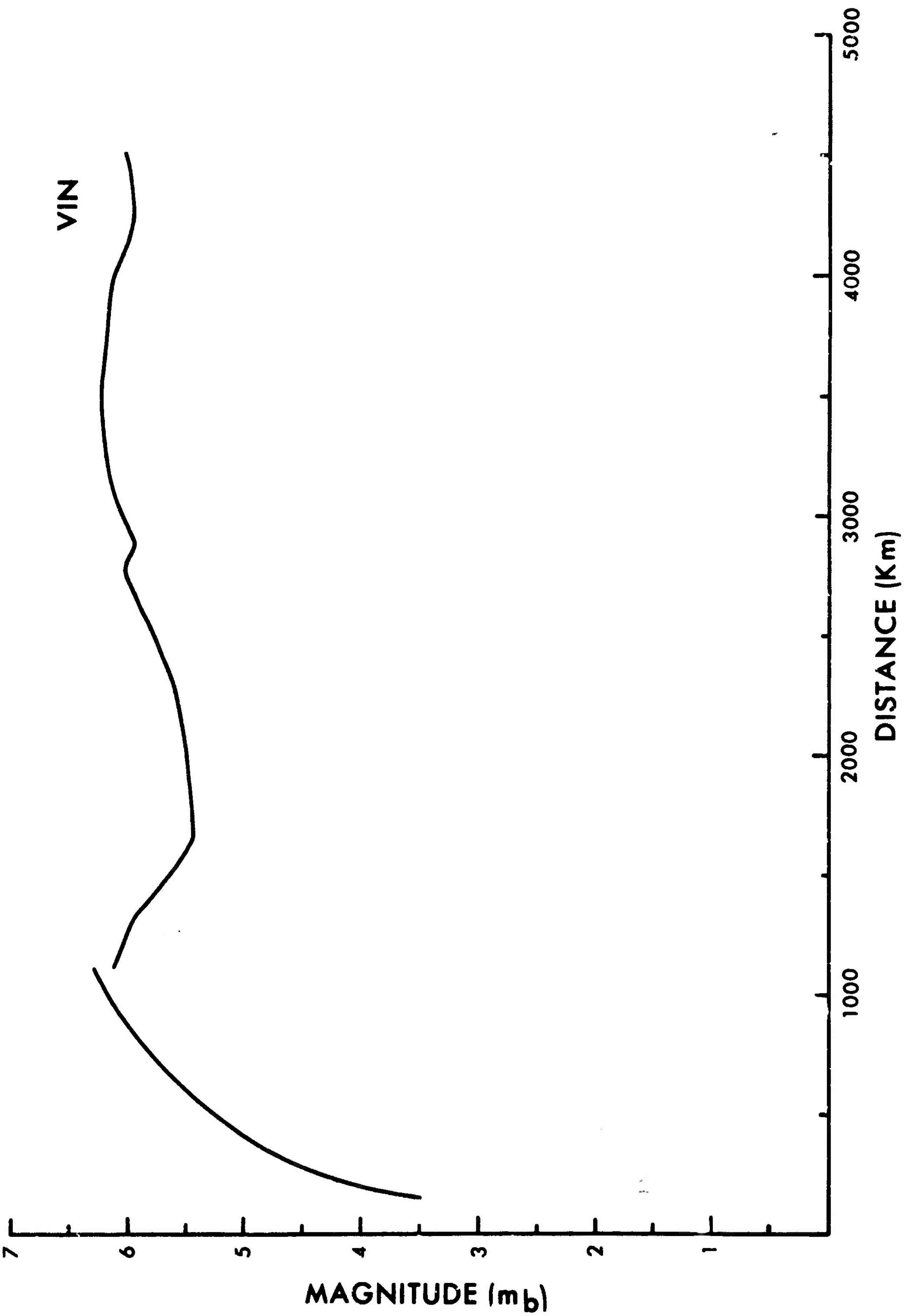
VIN
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MAGNITUDE (mb)
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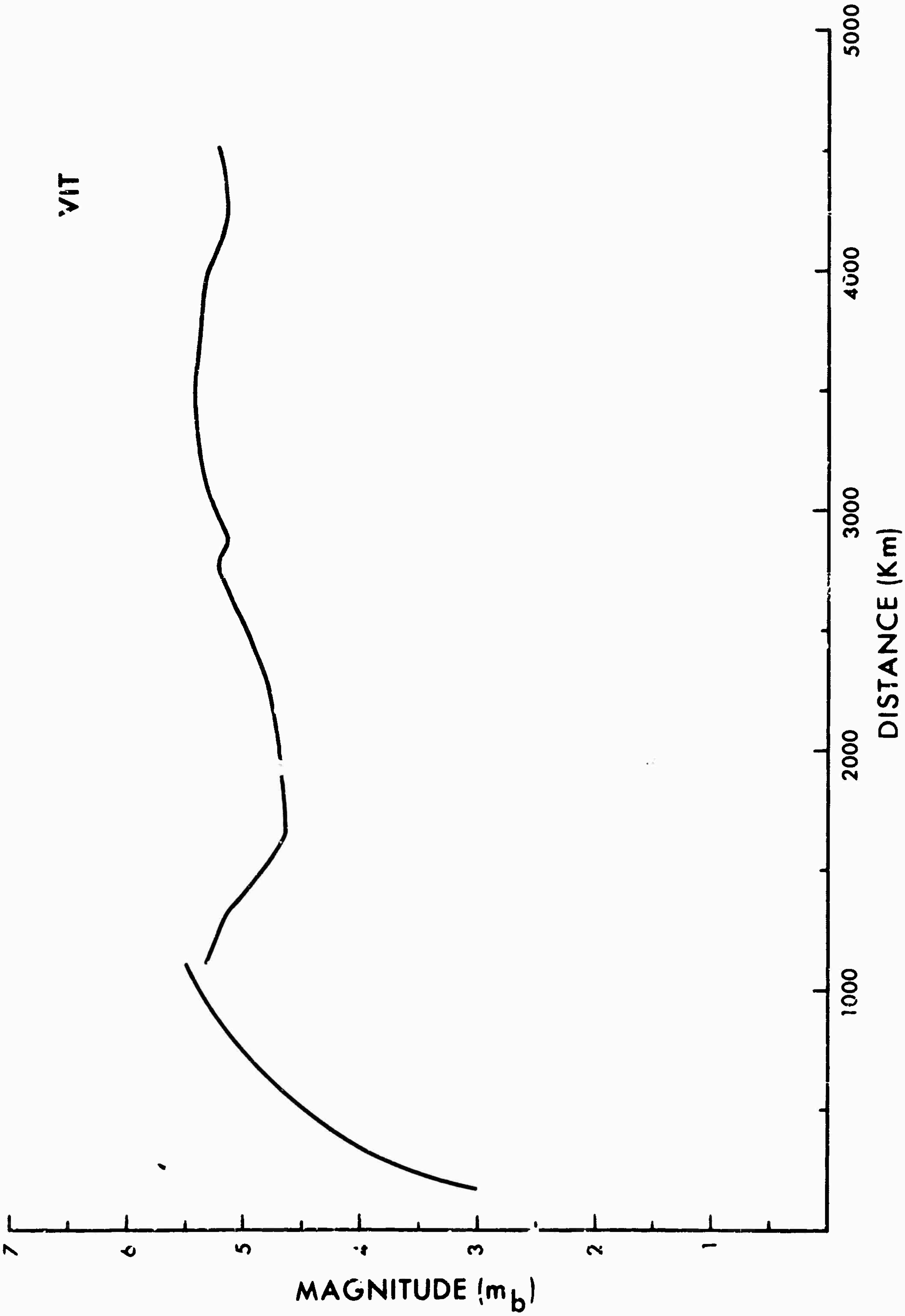
VIT
MAGNITUDE (m b)
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4
3
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1
1000
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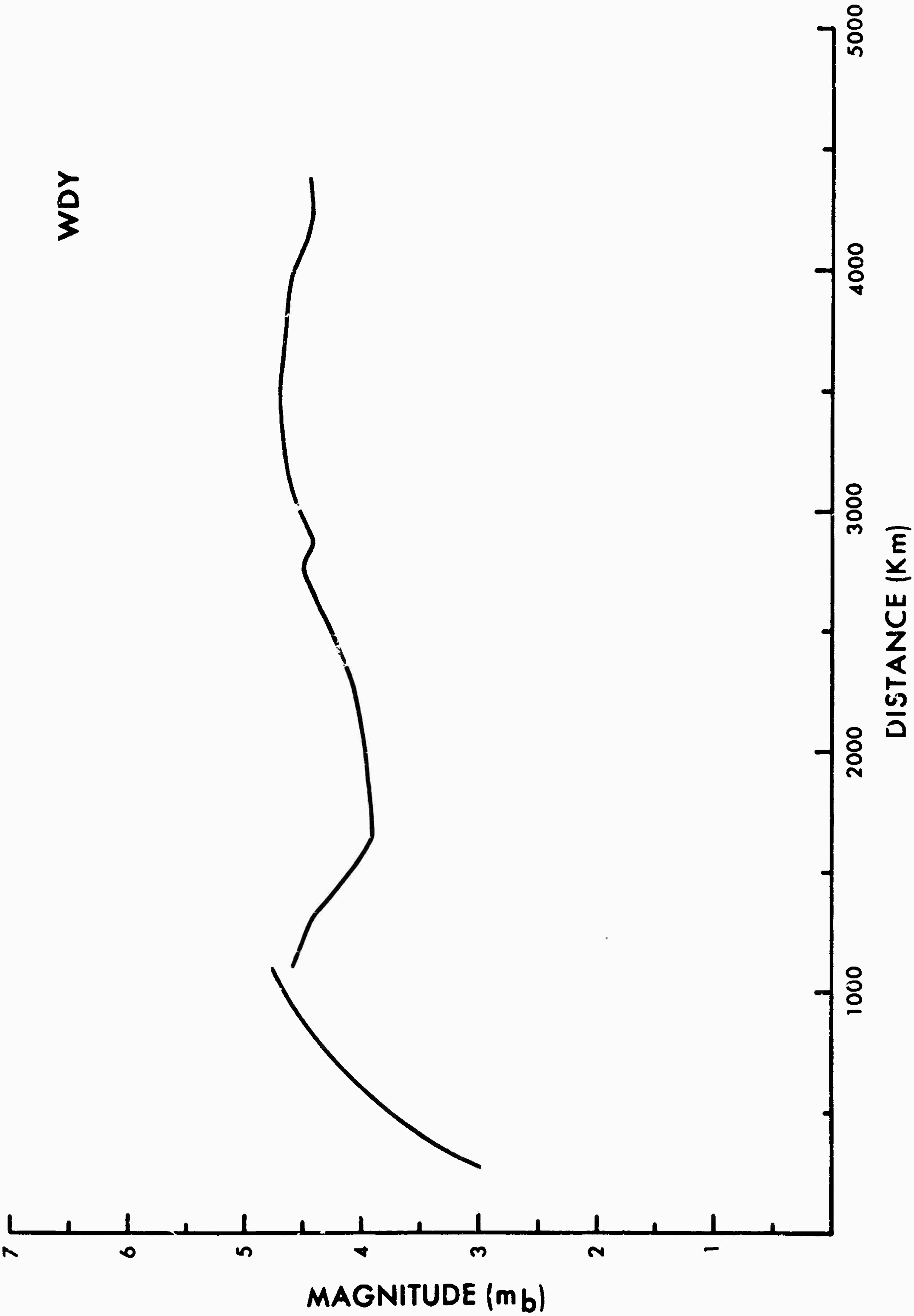
5000
DISTANCE (Km)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MAGNITUDE (mb)
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DISTANCE (Km)
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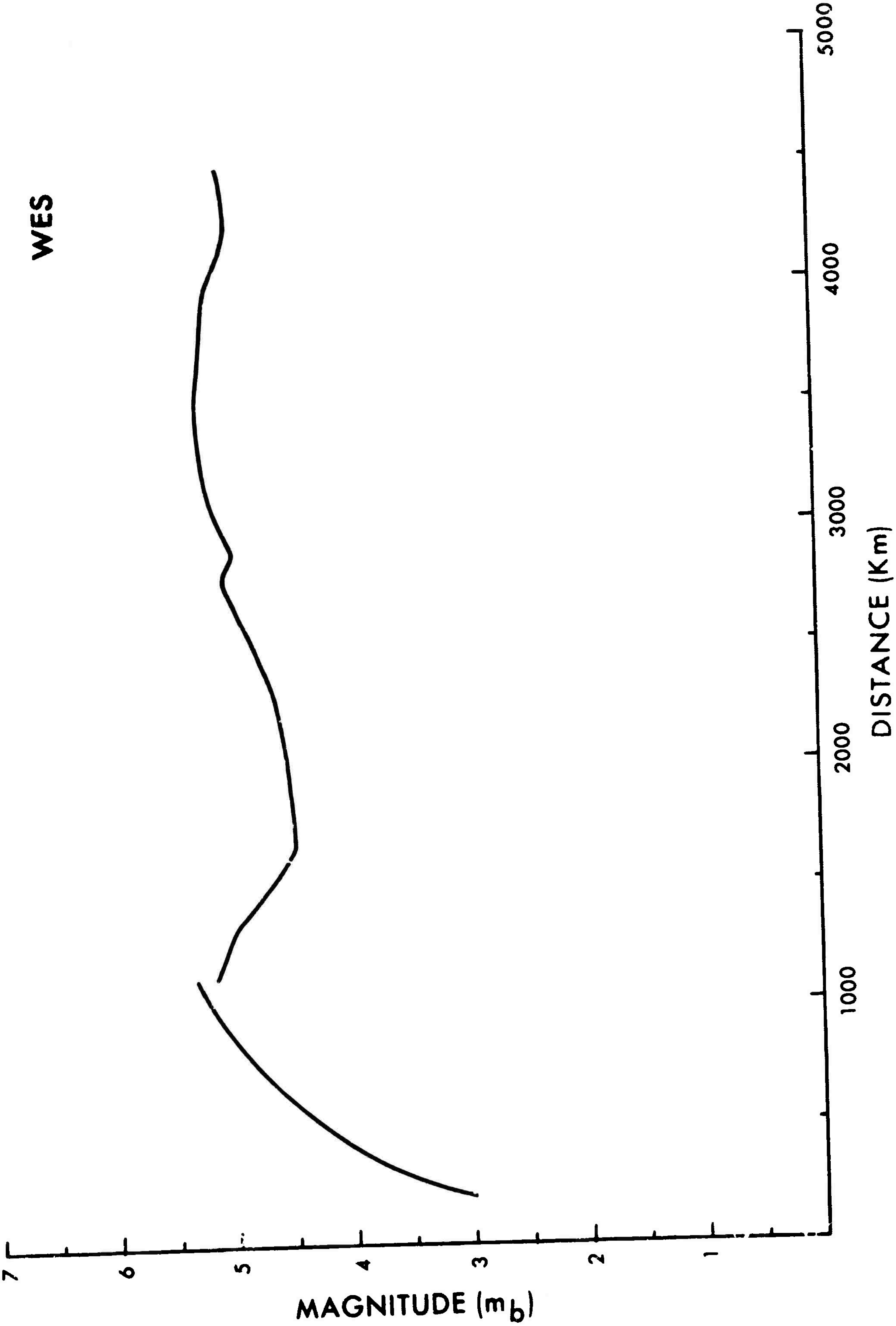
WES
MAGNITUDE (m_b)
DISTANCE (Km)
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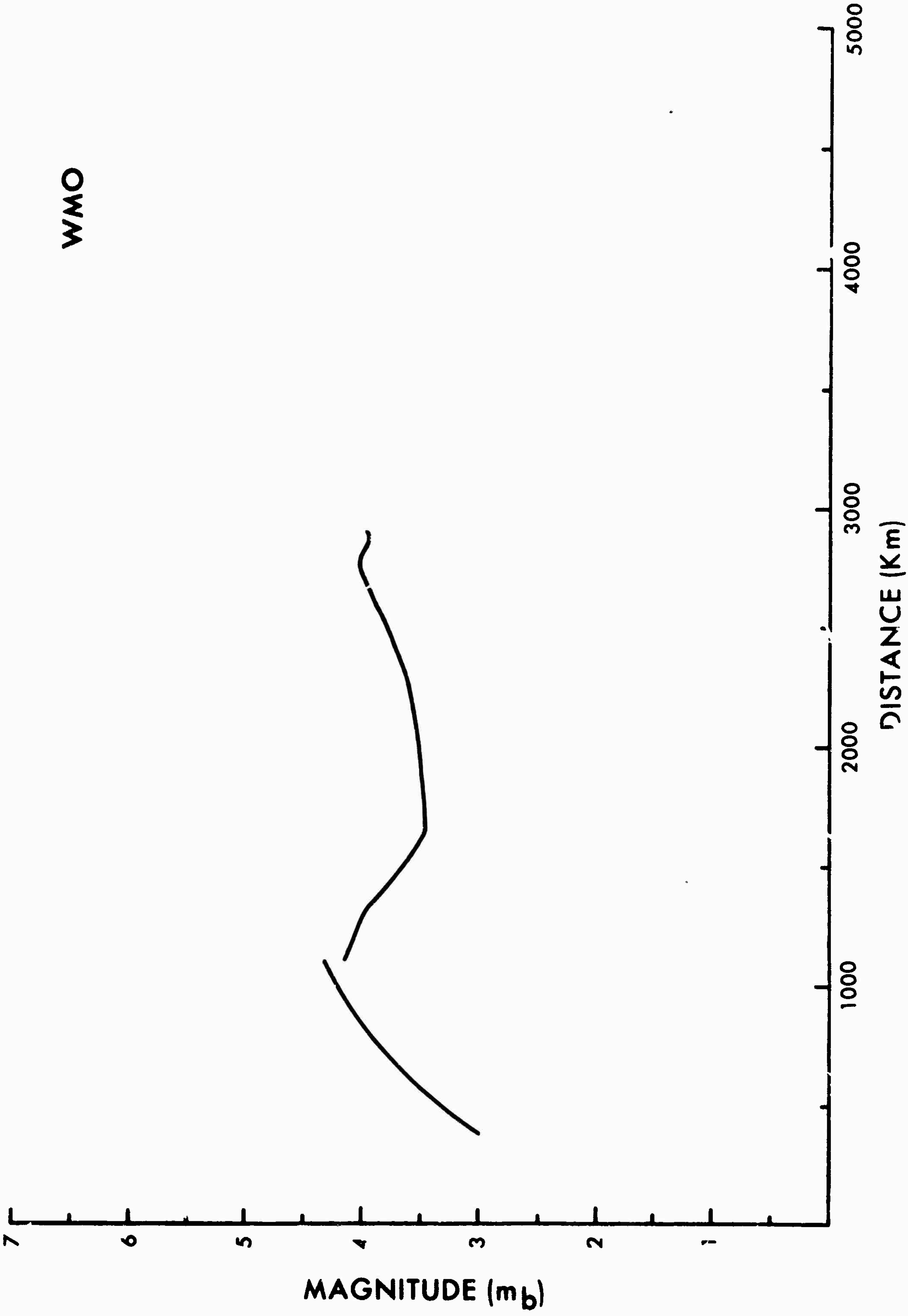
WMO
MAGNITUDE (m_b)
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DISTANCE (Km)
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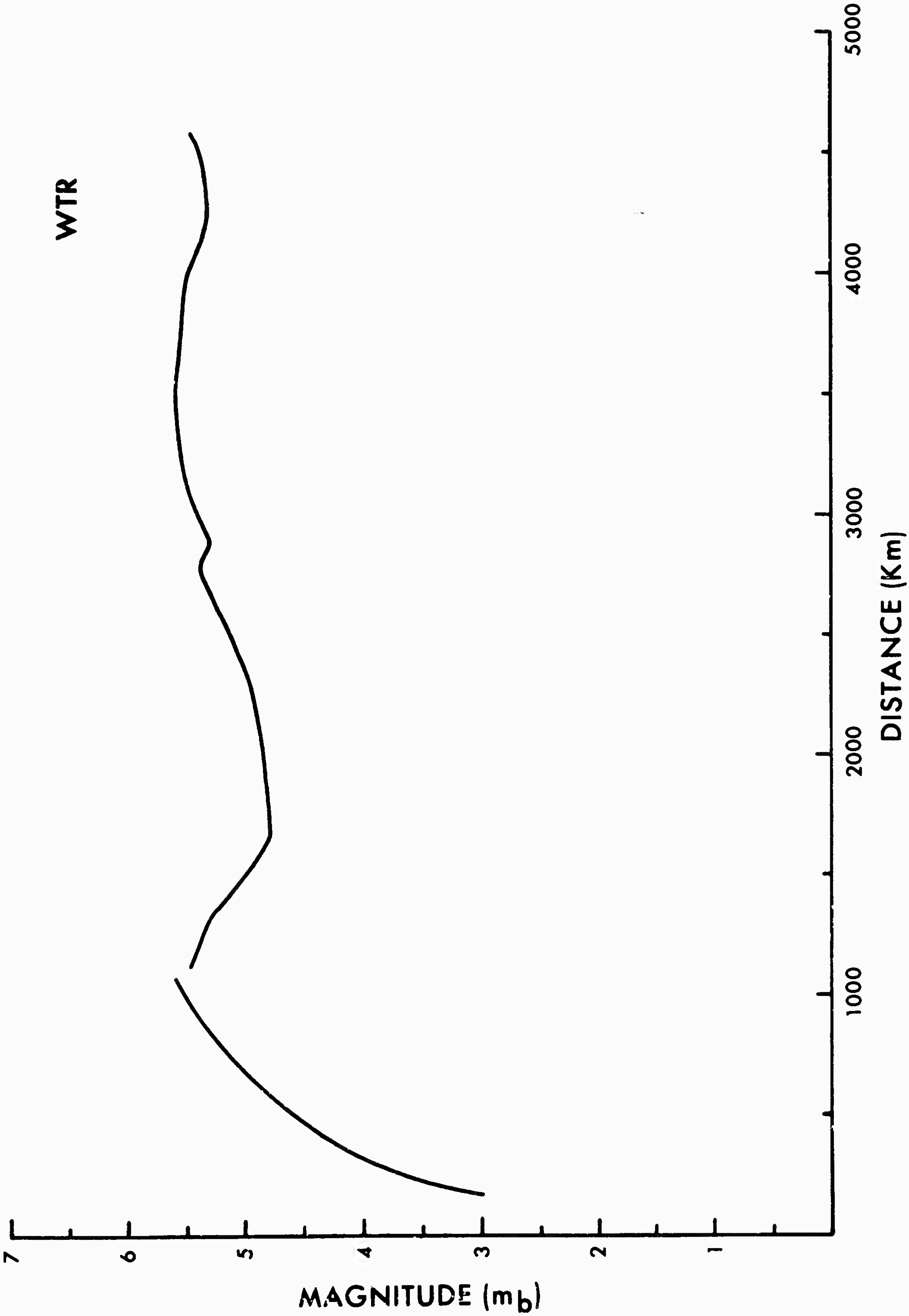
WTR
DISTANCE (Km)
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5000
MAGNITUDE (m_b)
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4
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